Design of Dies

DIE DESIGNS 165

for UPSETTING FORGING MACHINES

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Design of Dies for Upsetting Forging Machines

This booklet deals with the design of dies for Upsetting Forging Machines. Such machines, which are in general use today, employ three die elements, two matching gripper dies, one stationary and one moving, and headers or heading tools. It is the function of the machine to first close the moving gripper die against the stationary gripper die and hold it closed during the advance and withdrawal of the headers, then open the moving die.

The dies and forging machines under consideration embrace a considerable range of sizes, with capacity ratings based nominally on their ability to hot forge the heads on alloy steel bolts from 1″ diameter to 8″ diameter, or larger.

The Upsetting Process

In practically all Upsetting Forging Machines used today, both the die and header movements are horizontal, straight line and at right angles. Similarly, practically all are mechanically operated from a main shaft, which drives the moving die at right angles through toggles, and the header slide directly by an eccentric. Consequently, the gripper dies are not closed until the headers have traveled a portion of their forward stroke. The distance the headers travel forward after the gripper dies are closed, is termed the "stock gather" of the machine, and the distance the headers recede before the dies start to open, is termed the "hold-on". The distance the moving die travels is called the "die opening".

The cavities formed by the impressions in the two dies and the heading tools, frequently totally confine the working stock, so the hot metal can be subjected to hydrostatic-like pressure. This is a great advantage in filling out intricate forgings, as against the usual drop hammer die impressions, where there is a gap between the die faces while displacing stock, and the designer is constantly confronted with the problem of flowing metal into the remote parts of the impressions while a portion of it escapes between the faces of the dies to form flash. Also, since the forging machine die cavities open in two planes at right angles, a great variety of complex forgings can be filled out and removed from the dies readily, without serious problems of clearances and draft angles, which frequently place restrictions on the shapes that can be drop forged in hammer dies.

Forging on these machines is not limited to simply gripping and heading. The powerful action of the moving die, in addition to being used for gripping, may be used also for shearing, swaging, bending, flattening and punching.

Most write-ups on forging machine dies have dealt principally with the action of the headers, or heading tools, in upsetting or forming stock in the direction of the axis of the bar. But since the gripper dies act first and they perform their work ahead of the headers, it seems entirely logical to consider their design first.

Functions of Die Grooves

There are more problems involved in gripper grooves than appear at first glance. Except for a very minor amount of cold drawn, or centerless ground stock, most upsetting stock consists of hot rolled bars with usual mill tolerance. The grips must be small enough to hold bars on the low tolerance and, when the bars run at the top limit, must still close sufficiently tight to avoid formation of flash, or fins.

Other considerations are: 1—the length of gripping groove permitted by the shape and size of the forging, the limit of the die length of the machine, or the length of crop end, or tong hold, that can be thrown away at the end of the bar; 2—the severity of the heading operation and its tendency to drive the bar back through the grips; 3—the amount of distortion or out-of-roundness permissible on the shank of the forging, or on the gripped portion of the bar which is fed forward to make the next forging; 4—the temperature of the bar in the grips; and 5—does the bar have to be gripped repeatedly at the same location for a series of operations, or will the grip for a subsequent forging overlap the part of the bar which has already been subjected to grip?

If the stock is comparatively cold and non-plastic in the grip location, it is the usual practice in machining, to clamp the dies together for boring,

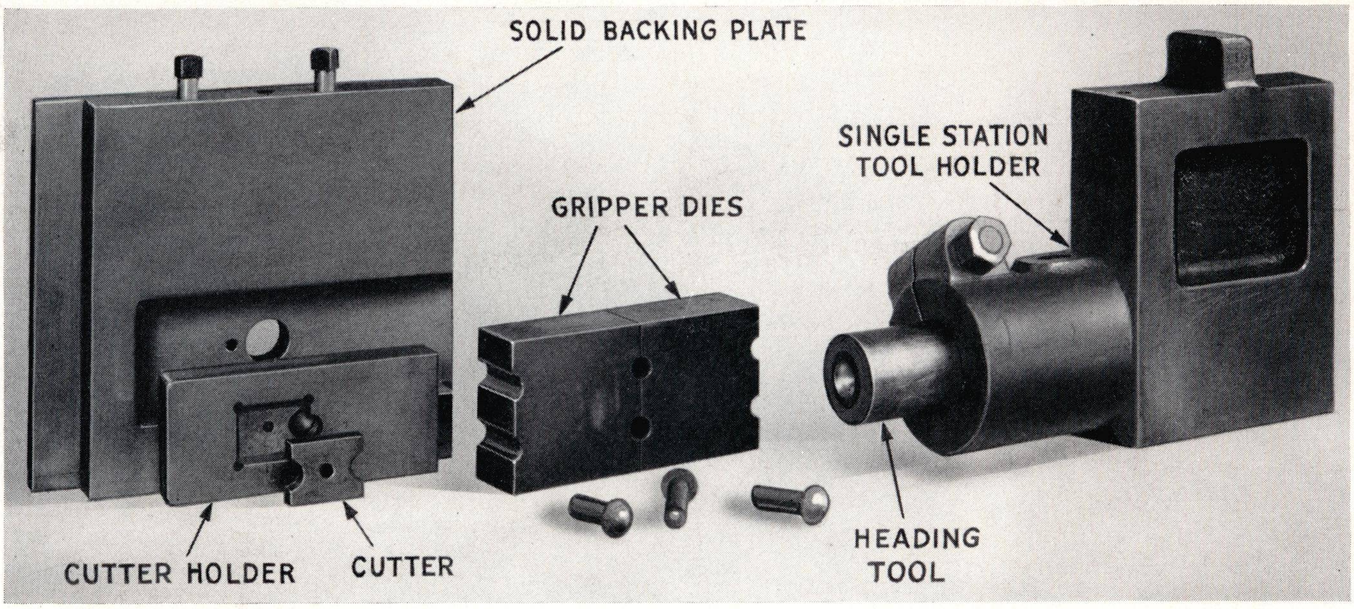


Fig. 1. Button head rivet dies.

with enough thickness of shims between them to equal the tolerance of the stock, plus from .005″ to .015″, and bore to the large stock size, plus some allowance for expansion at the temperature still below forging range. The edges of the grooves are then ground back sufficiently at a draft angle of about 10°, so as to accommodate the stock without pinching a fin, or flash, adjacent to the upset. With comparatively cold stock 3½″ or 4″ length of grip is usually adequate for stock of 1″ diameter, or less. For larger stock the grip length should be roughly from 3 times to 4 times the diameter.

In the button head rivet dies, Fig. 1, the grip problem is solved automatically. The length of the grip is determined by the length of shank, the diameter not by the tolerance of the bar, but by the diameter desired on the rivet. The cutter plate through which the stock is fed and sheared off by the moving die, backs up the blank so it cannot slip back during the heading. As the bar is hot over-all, heading upsets the stock to the size of the grip sufficiently tight to pull the head out of the header impression on the return stroke, and the ejector pin through the cutter, kicks the piece out of the dies when they open. If a square or hex head bolt is made by this method, it may not be held sufficiently tight in the grips to pull out of the deeper, straight-sided recesses in the header and a header ejector may be added.

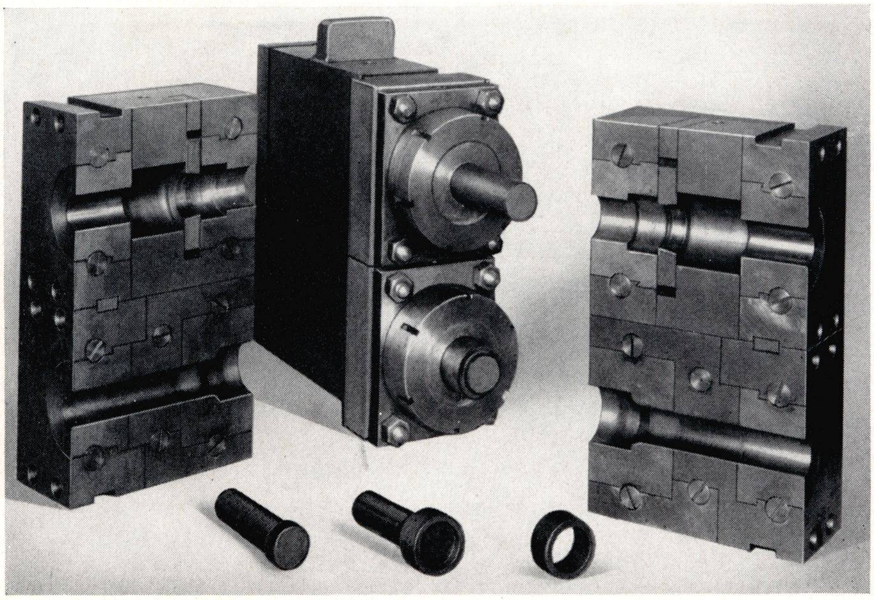


Fig. 2. Dies for upsetting ball bearing races.

Ball bearing races are made by starting with eight or ten foot bars. The ring is first upset in the bottom die groove, Fig. 2, then the bar punched out at the top of the dies. Enough bar length is heated to make 6 or 8 forgings in succession and only a short length of bar is fed forward for each ring. Here the grip is in three steps of successively smaller diameter, so as to get a hold on three times the length of bar that is fed forward. There is, of course, no grip in the top position where the bar is punched back through the ring. The enlarged punch slug on the end of the bar serves as a preliminary upset for the next forging.

Sometimes when the bar is at forging temperature back through the grips, it will be necessary to bore the grips with corrugations, which

actually bite into the stock. The corrugations should be high enough to groove the bar, but sufficiently rounded to prevent the grooves from showing up on the surface of the forging when the bar is fed forward. In the case of the three high cylinder dies, Fig. 3, the bar surface is ironed smooth by a smaller smooth section in the grips just behind the forging impression.

Fig. 4, are general-purpose three high holders for half round die inserts. They are being used for only a two high forging job, the center position being for upsetting an outside race for a tapered roller bearing, and the bottom position for punching out the bar with merely a free guide for the bar at the back of the dies. Here again the corrugation is ironed smooth by the grip at the back of forging impression insert.

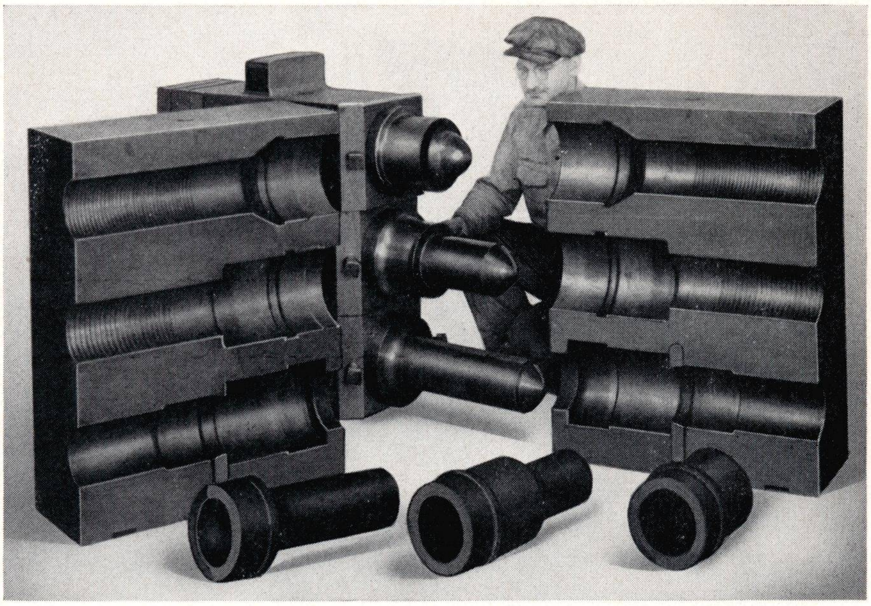


Fig. 3. Three high cylinder dies with corrugated grips.

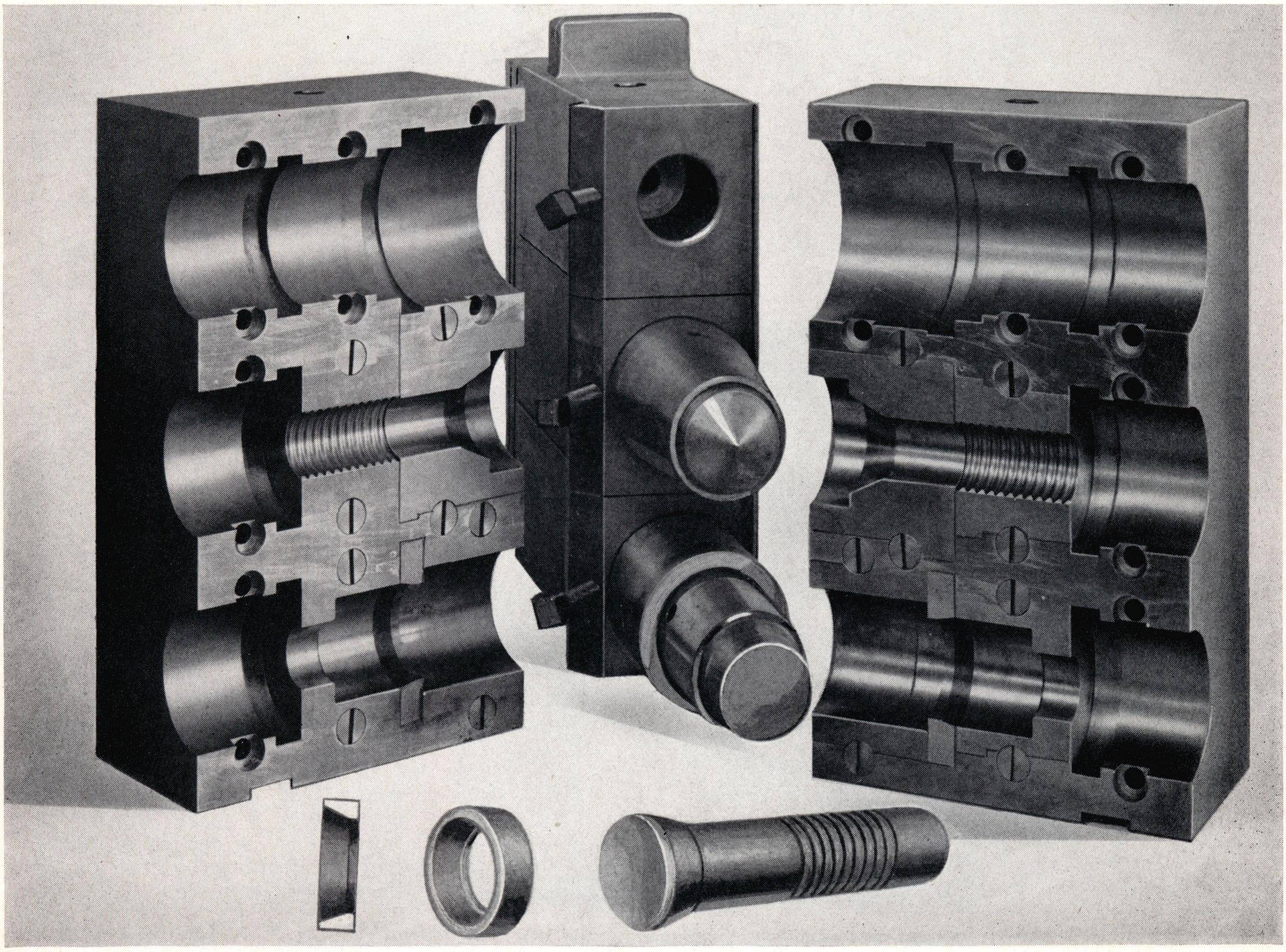


Fig. 4. Three high holders for half round die inserts.

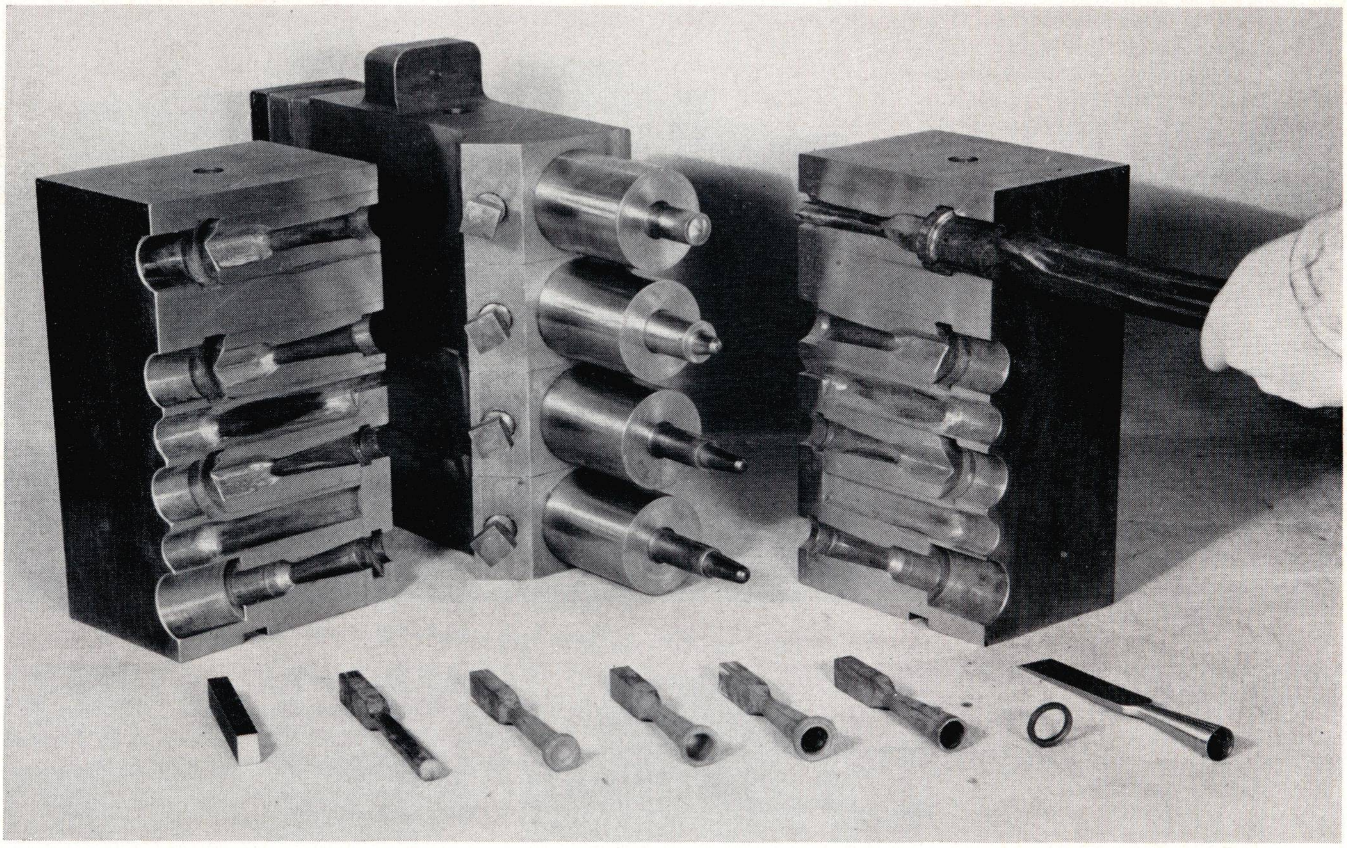


Fig. 5. Dies for upsetting the handle socket for a carpenter chisel.

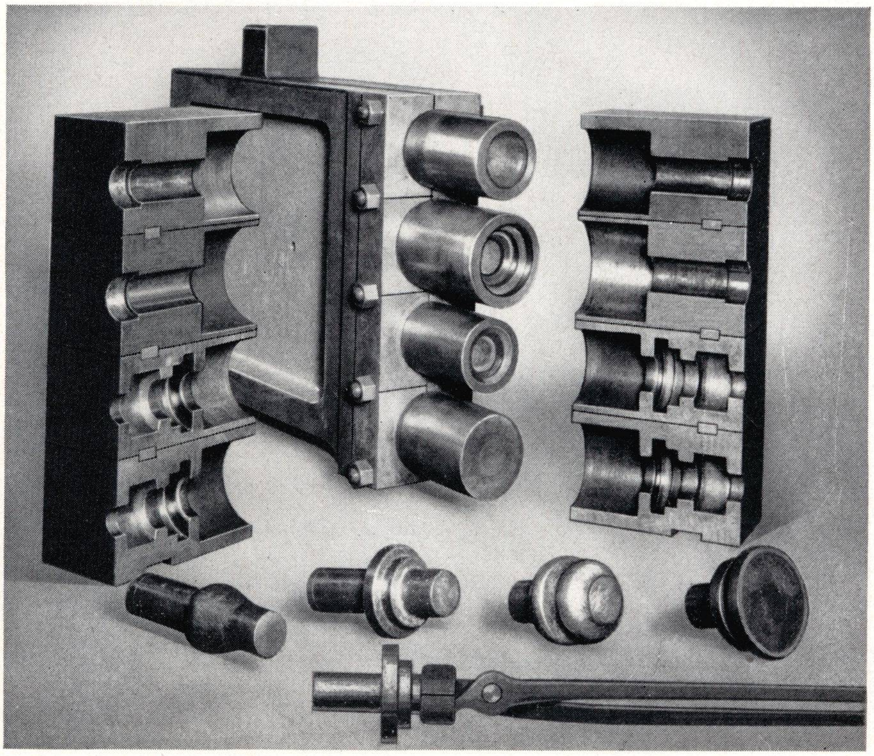


Fig. 6. Dies for automobile transmission cluster gear.

If the bar is to remain as a shank on the forging, the ridges may be smoothed out in the grip of a subsequent operation, after a shoulder has been upset, which will lend support against slipping back through the dies.

The dies for upsetting the handle socket for a carpenter chisel, Fig. 5, on rectangular stock are interesting from several viewpoints. A section of the stock is first swaged into a tapered round between the dies. This leaves too short a length for proper gripping, so "insert tongs" are used which lock into the die impressions to prevent slipping. After an upset and two tapered pierces to form the socket, a ring-shaped flash is trimmed off the end. The blade is later drawn to length and tapered in an AJAX Forging Roll.

In the dies for the automobile transmission cluster gear, Fig. 6, made from a blank sheared to length, there is enough length of grip for upsetting the small end in the two top impressions. The piece

is then laid down on a small turntable at the front of the machine, turned, and the end that is already upset grasped with insert tongs. These tongs pocket in the cavities at the rear of the two lower forging impressions, and really serve as a die element while the large gear is gathered and forged to dimensions.

Insulator pins, for telephone and power lines, have ample bolt length for a liberal length of die grip, Fig. 7, when made for use with wooden cross arms on the poles. The working stock is sometimes so long it projects into the hollow header where the usual swinging stock gauge cannot be used. Instead the tongs are used for a gauge against a stop block at the rear of the top groove of the stationary die. In these dies the collar is finished by transferring to the lower impression and a perfectly sound forging is produced.

When these pins are used on steel cross arms, the bolt end is only about 1½" long, which is entirely too short for die grip. To make them, the blanks are sheared a little longer than required for two. One end of the blank is heated and the one pin upset and then, after heating, the upset pin serves as a tong hold while upsetting the second pin. The two pins are then cold sheared to length, discarding the short piece between, which was necessary to make up enough length for die grip.

In actual production most insulator pin forgings are made in a single die groove by double gauging; upset once, then pushed forward in the die and hit a second time. The double gauging can be accomplished with the tongs by having the jaws of different lengths and the gauging abutment on only the stationary die. Rotating the tongs 90° after the first blow, brings the short jaw against the stop for the second blow.

In forging the double-flanged insulator bolt, Fig. 8, the length of the straight ends and diameter of the flanges would prevent removal from the dies, if upset in a hollow header with straight bore which would not clear the end on back stroke. A sliding die provides for accurate gauging against an abutment at the forward end of the groove in the stationary die slide-block and permits easy transfer after the first flange is upset. This flange is pulled back into a cavity in the lower groove, where the second flange is

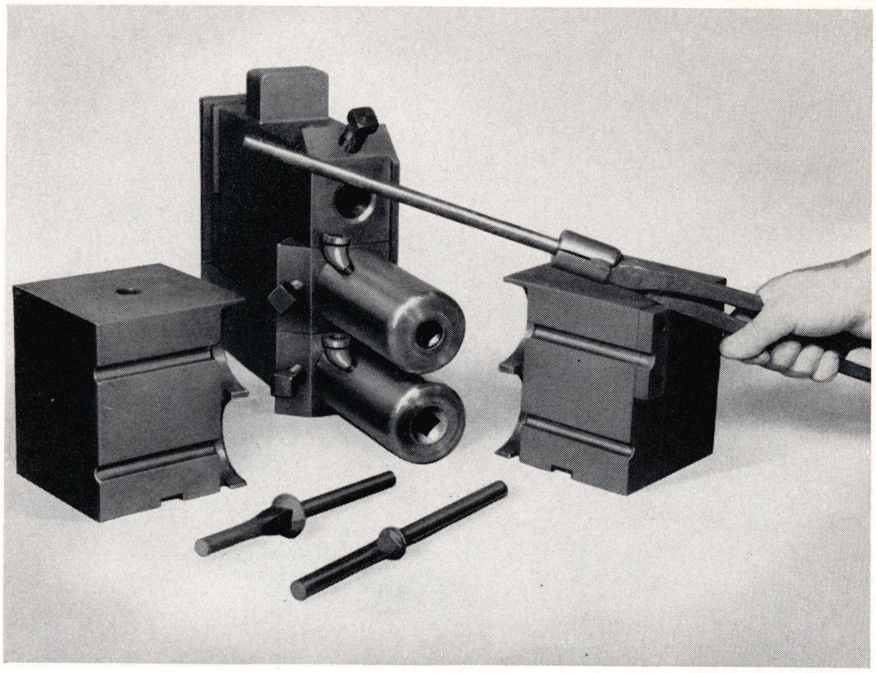


Fig. 7. Tongs used for a gauge against a stop block.

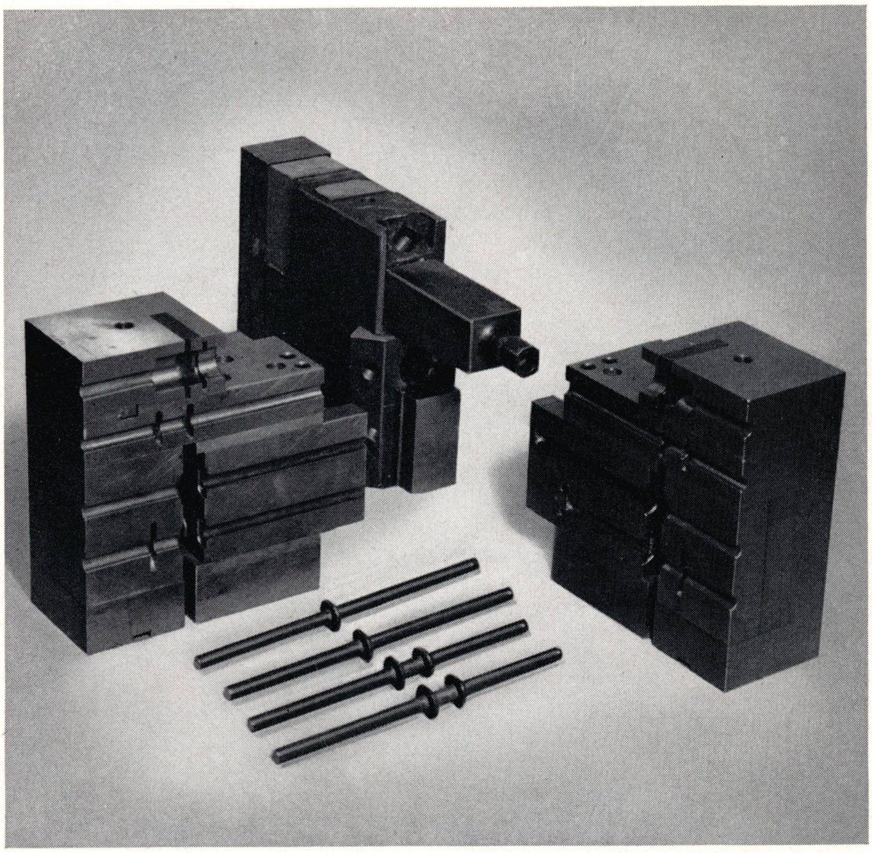


Fig. 8. Dies for insulator pins with two flanges.

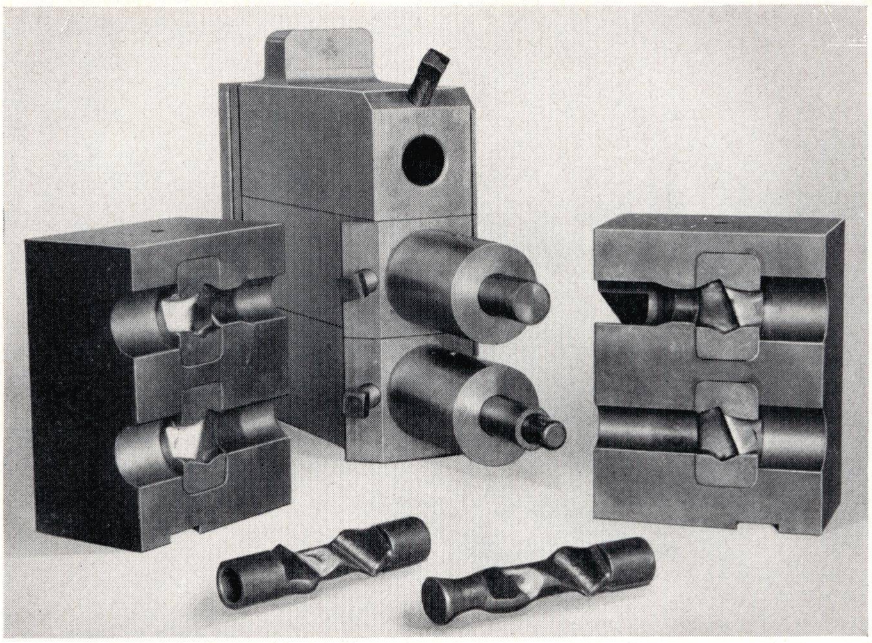


Fig. 9. Dies for forging cross-bar end for tubular airplane strut member.

formed. Swaging in the groove above the slide blocks rounds up the ends perfectly and trimming in the top pass removes flash from the flats on the edges of the flanges.

In forging the cross-boss end for a tubular airplane strut member, Fig. 9, shortness of die grip is carried to the ultimate. The gripper dies in closing, pinch the double ended blank almost in two, leaving a web about $\frac{1}{8}''$ thick and flattening the stock for the cross-boss. At the same time the header upsets the end of the bar into a reverse cone, as shown in foreground. Fig. 9

In the second operation, the dies reduce the web to $\frac{1}{16}''$ thickness, preventing stock from escaping from the impression. The reverse cone centers the end for piercing by the displacement punch, which forges the socket section and completely fills out the cross-boss. After the second forging is made from the other end of the blank, the two are

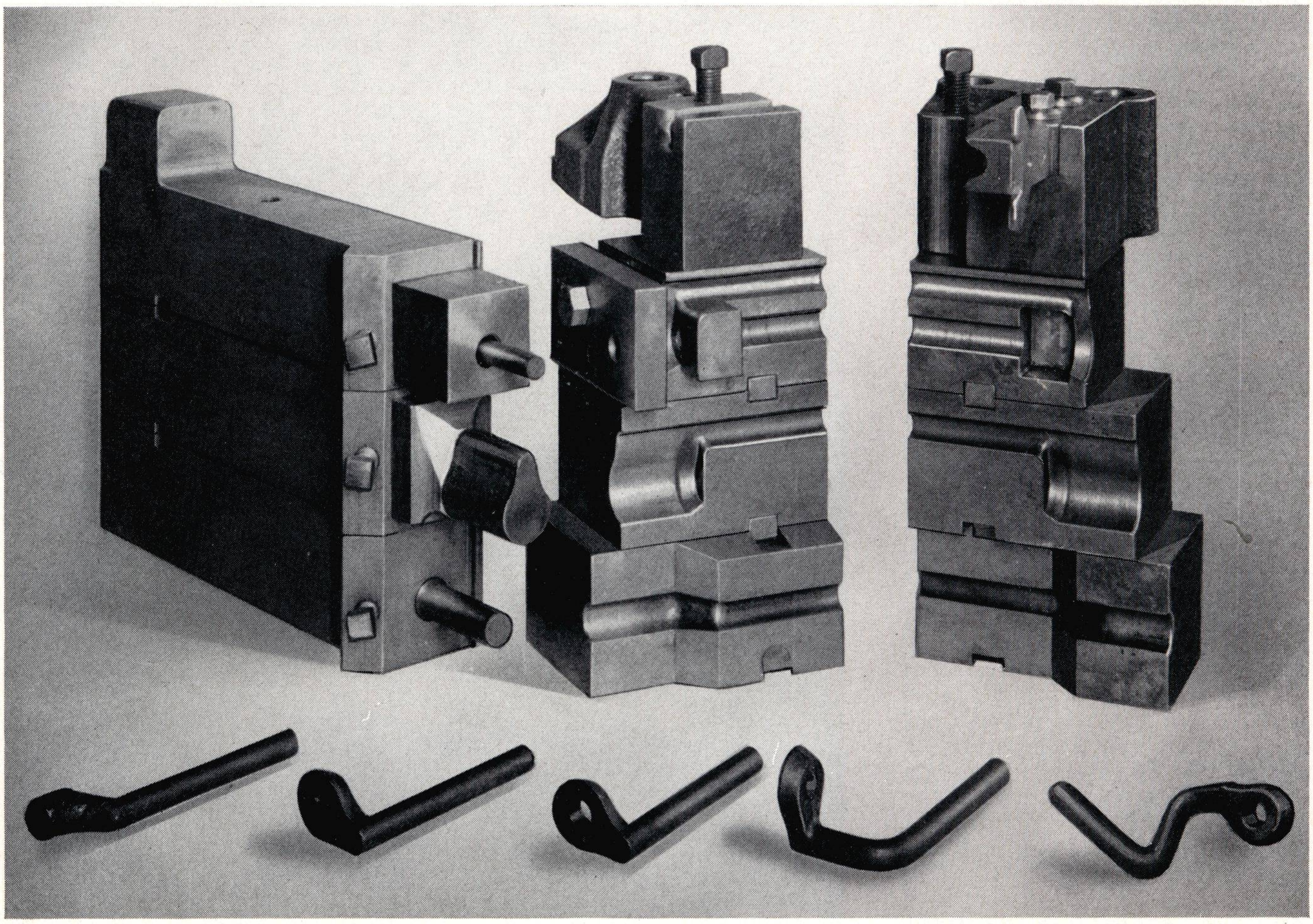


Fig. 10. Dies for railroad grab iron illustrate bending with the moving die.

sheared apart and butt welded to the ends of a tube of the same O.D., I.D. and wall thickness as the socket.

The railroad grab iron die and tool setup, Fig. 10, is an illustration of bending with the moving die. In the first operation at the bottom, the moving die in closing bends the bar, so that the heading tool forms an off-center upset. When the blank is rotated 90° in the impression above, this locates the stock just right to fill out the pear-shaped foot. Punching of the hole is done against an abutment projecting from the stationary die, so as to give a perfect seat for the rivet head and avoid any ridge which might form, if the punching were done against a split punch plate.

The piece is then held in a groove in the top of the stationary die clamp and bent by a projection on the moving die clamp. The second right angle bend is made by pushing the piece forward in this same groove and closing the dies a second time.

The harrow tooth dies, Fig. 11, first gather the diamond section stock in a cylindrical die groove and then a rectangular die groove. The upset is next located in an impression between these grooves where the closing of the dies forges the upset stock to the correct foot shape to fit snugly the member to which it is later bolted.

Finally in the bottom position, a punch carried by moving die, punches the hole and the forging is stripped from the punch by the stripper plate, which in this instance is spring supported on the stationary die so that it flattens the piece after punching, and eliminates suck-in at the hole.

In the step gear die, Fig. 12, the smaller gear is upset between the face of the die and the header, with a considerable length of stock projecting into the header. This enlargement is then placed in a groove back in the grips of the middle impression where the larger gear is upset. The forging is then simply sheared off the bar by the moving die in the lower position, where there is no header.

A hub which is upset from rather large stock, Fig. 13, is similarly sheared off in the lower die position but, after shearing, while still securely gripped, the small hole is punched, wasting only the punch slug. This leaves the bar end in satisfactory

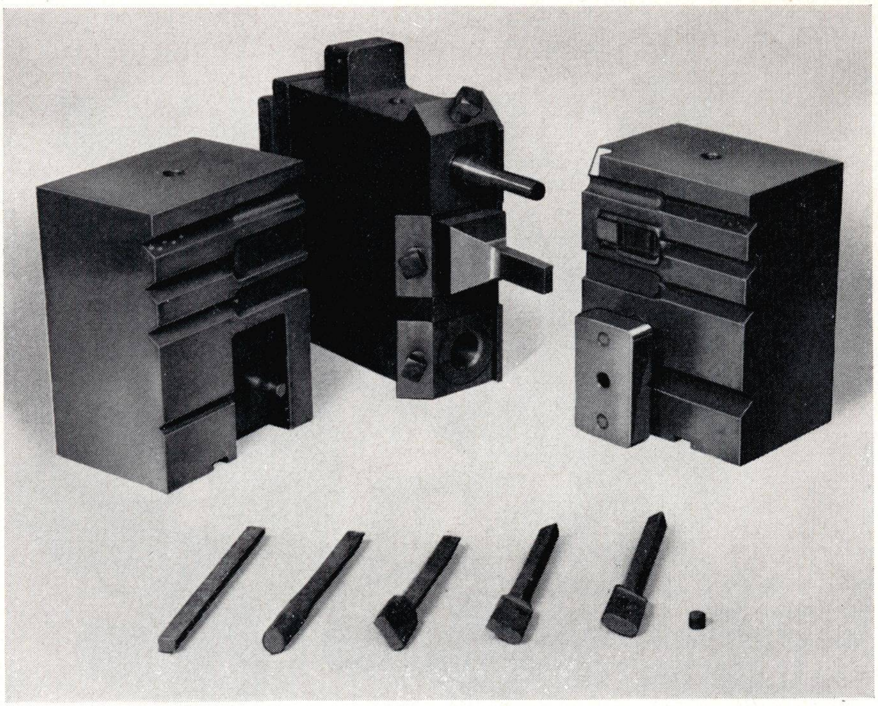


Fig. 11. Harrow tooth die.

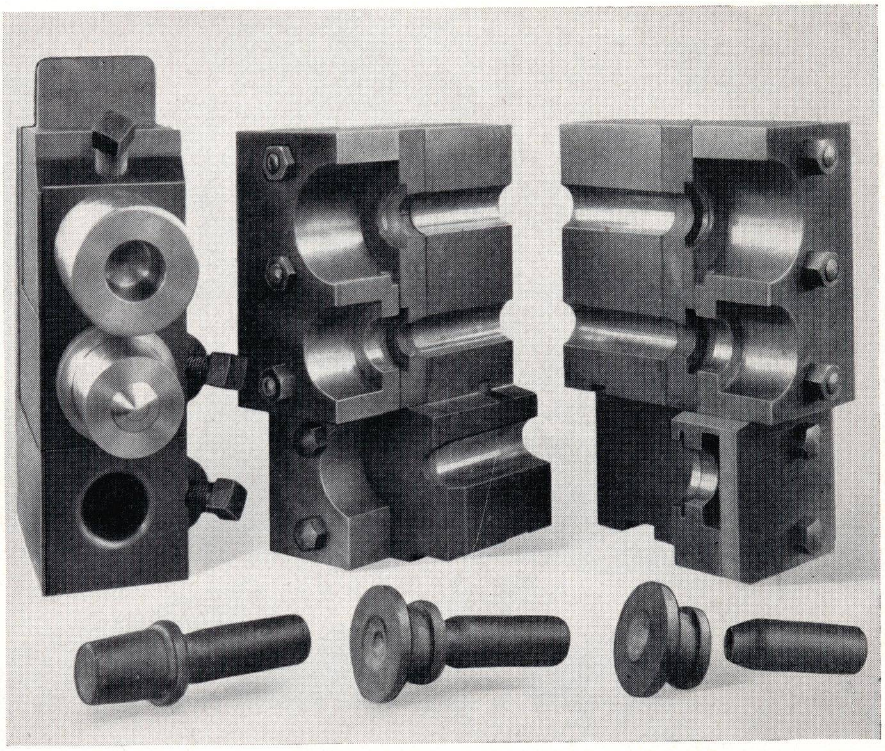


Fig. 12. Step tooth dies.

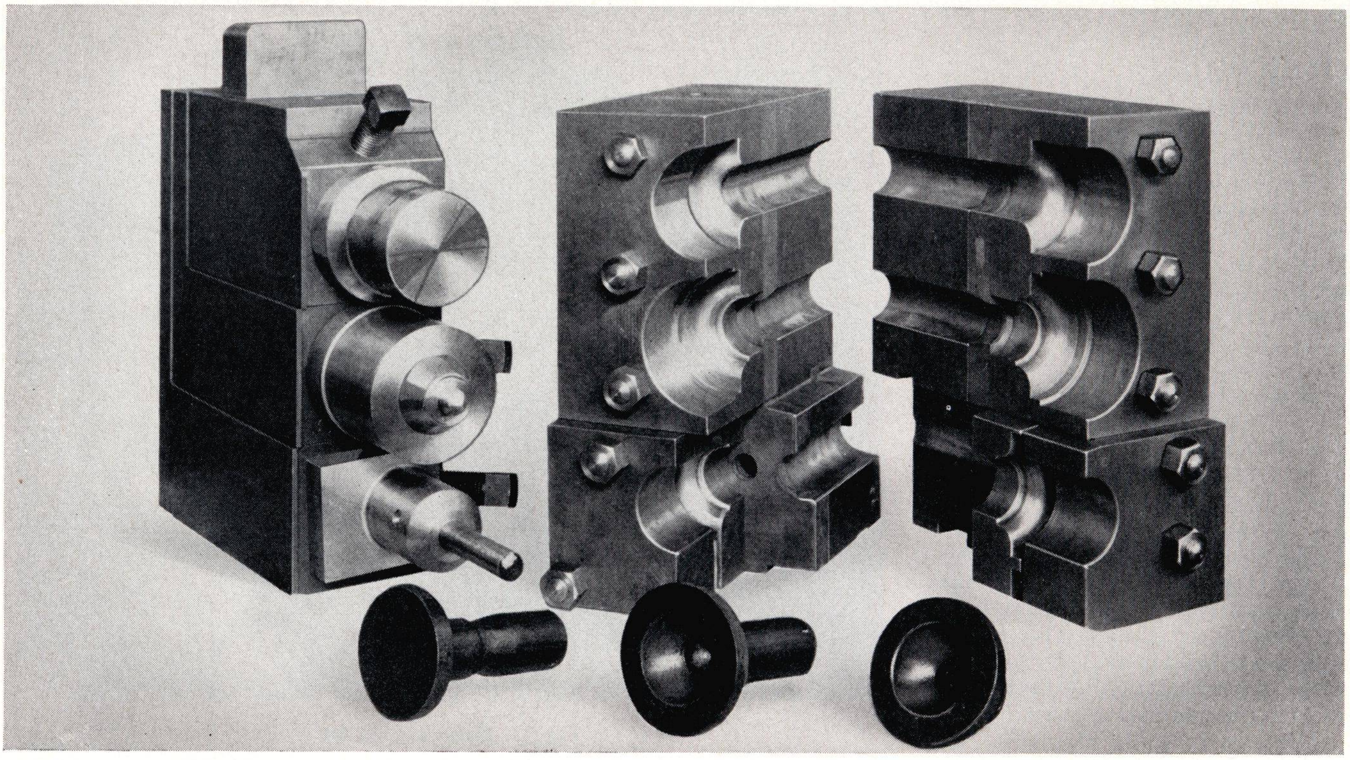


Fig. 13. Hub upset from large stock.

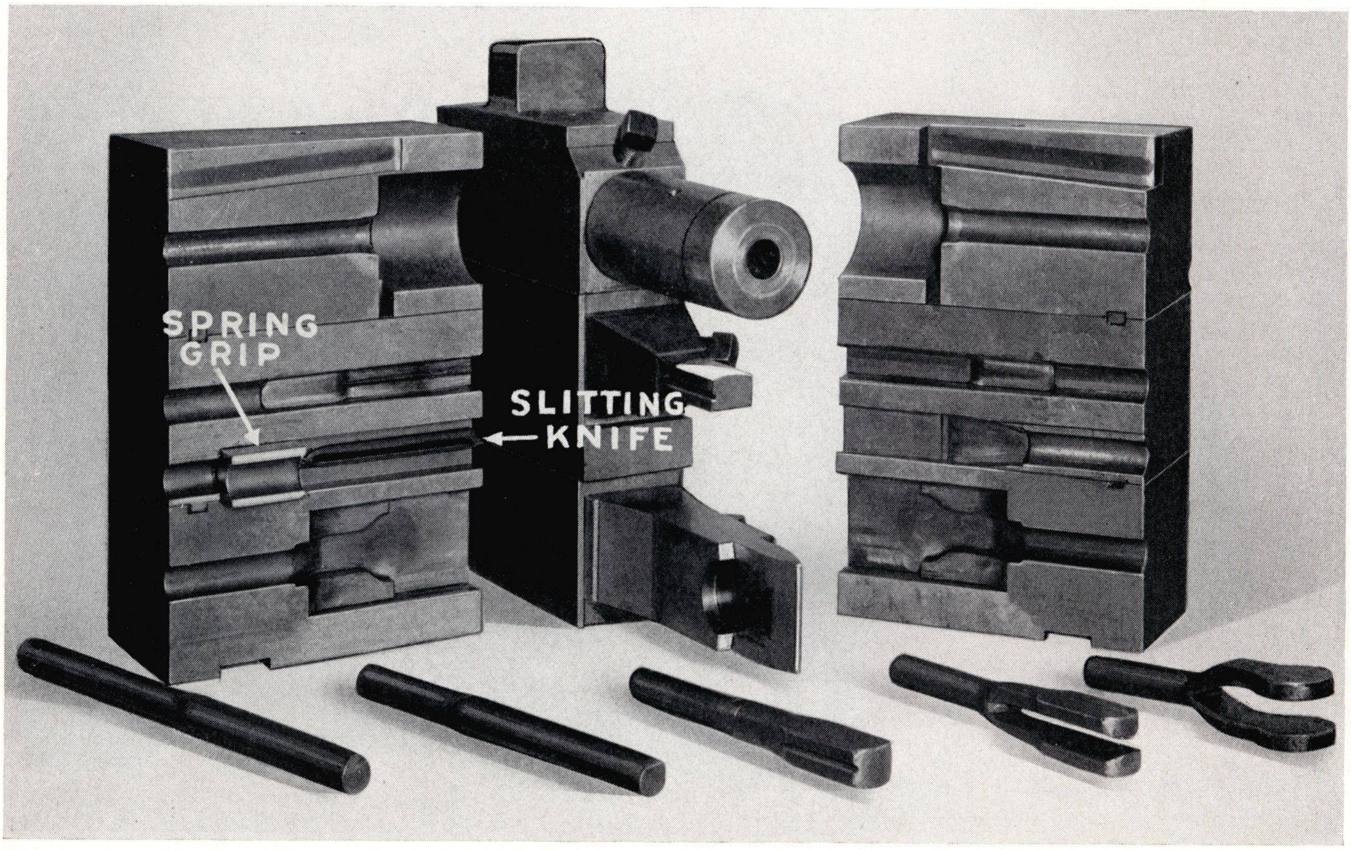


Fig. 14. Moving die can be employed for slitting.

condition to go into the next forging without danger of folds or cold shuts, which would result if the small punch slug remained on the end of the bar.

The jaw forging, Fig. 14, illustrates how the moving die can be employed for still another operation —slitting. After the required stock has been gathered into a slightly grooved, rectangular upset, it is placed in the impression next to the bottom. As the moving die closes, a spring supported block grips the bar and holds it firmly, while the knife, carried by the moving die, slits it halfway through. This spring block also strips the piece off the knife as the dies open. The piece is rotated 180° and then slit completely through.

From there the forging is transferred to the bottom die, where the heading tool opens up the jaw and upsets the enlarged ends to accommodate the holes for the cross-pin.

Thus far we have dealt with some of the operations which can be performed in the dies in addition to their usual work of gripping. Now let us transfer our attention to the primary function of the machine, which is heading or upsetting.

Heading or Upsetting

It is seldom the stock gather of the machine, that is, the length of headerslide stroke remaining after the dies are closed, which determines the amount of upsetting that can be done in a single operation, or the number of operations required to make a forging. More often it is the diameter and length of working stock, and the shape of the forging itself.

"Working stock", so far as the upsetting is concerned, is that part of the stock projecting beyond the die grips which is acted upon and changed in shape by the headers.

Successive upsetting operations should each fill the die impressions, or tool recesses, completely, consequently, be of the same volume and free from defects which would be embedded by subsequent operations. Aside from fins or flash, internal folds terminating in closed folds at the surface, called "cold shuts", are the most common defects to be avoided.

There are generally recognized rules, arrived at empirically, which govern the upsetting or gathering of stock to produce sound forgings and avoid cold shuts, but it should be borne in mind that these rules are flexible.

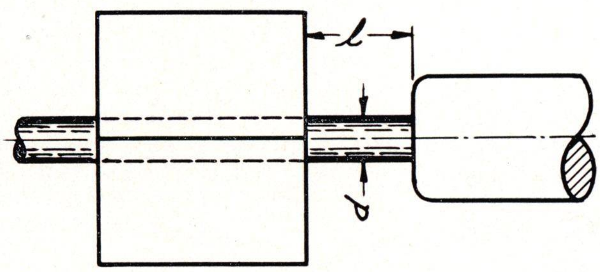
In RULE I, stock is "exposed" even when within a die impression or heading tool recess of too great diameter to lend support. If a length of the end of the stock projects into a tight fitting recess in the heading tool, that length is neither "exposed" nor "working" stock, and RULE I still applies.

Good, unvarying results will not be obtained if this working limit is exceeded, even when the stock is absolutely square on the end. If a perfectly centered, well filled out upset is required, with stock near this limit, it is frequently desirable to use a second operation.

The ¾″ U.S. standard hexagonal head bolt, Fig. 15, is an example of this. The length of working stock falls well within the 2½d limit for one upset. But to assure a well-filled head, without flash, the initial upset

RULES FOR UPSETTING

UNSUPPORTED WORKING STOCK – ONE BLOW



RULE I. EXPOSED WORKING STOCK UP TO A MAXIMUM LENGTH OF THREE DIAMETERS CAN BE UPSET WITHOUT SUPPORT TO PREVENT BENDING.

WORKING RECOMMENDATION

l SHOULD NOT EXCEED $2\frac{1}{2} \times d$

STOCK IS "EXPOSED" EVEN WHEN WITHIN A DIE IMRESSION OR HEADING TOOL RECESS OF TOO GREAT DIAMETER TO LEND SUPPORT. IF A LENGTH OF THE END OF THE STOCK PROJECTS INTO A TIGHT FITTING RECESS IN THE HEADING TOOL, THAT LENGTH IS NEITHER "EXPOSED" NOR "WORKING" STOCK AND RULE I STILL APPLIES.

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RULE I

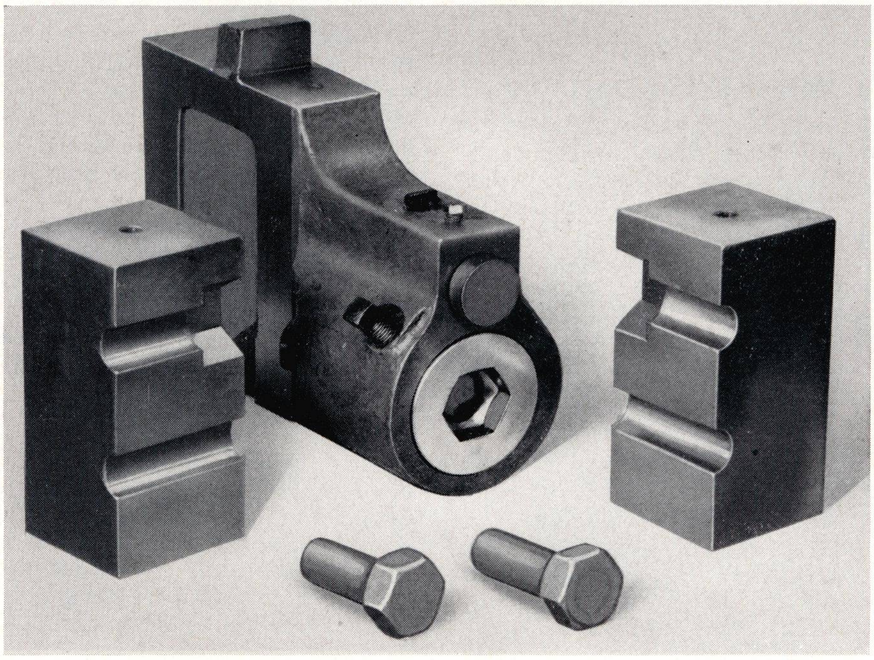


Fig. 15. ¾″ Hexagonal head bolt—an example of use of second operation.

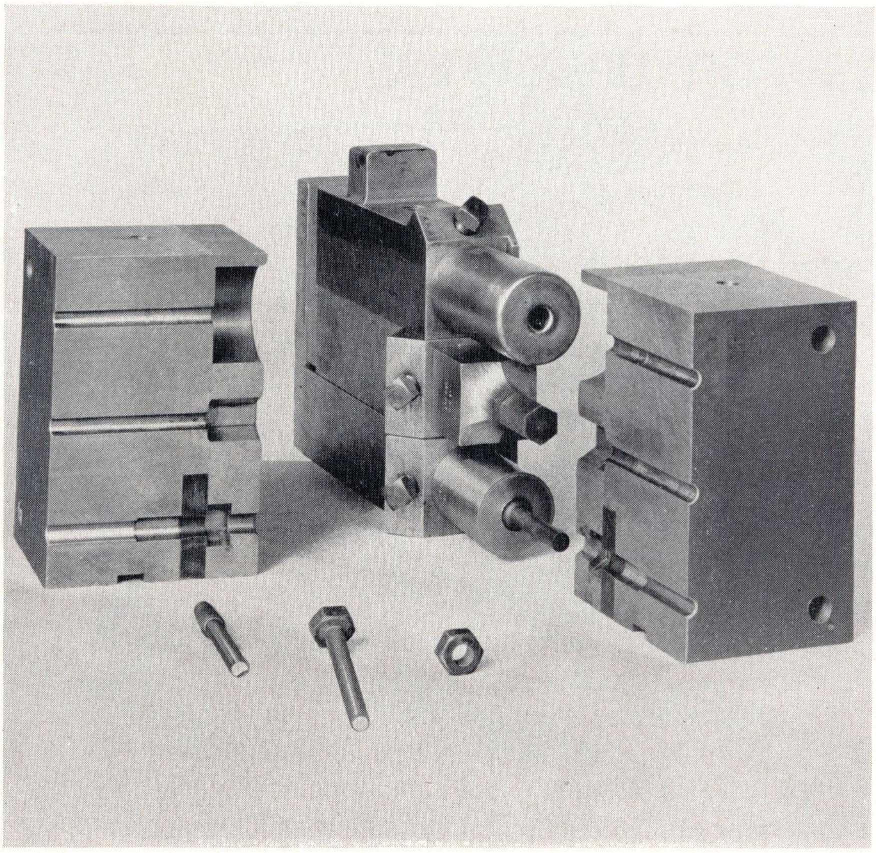


Fig. 16. Dies for forging nuts off the end of a bar.

is made in the thimble header at the bottom, then transferred to the hexagonal die impression at the top for sharpening up the corners and crowning.

In forging nuts off the end of a bar of the diameter of the hole for the tap, Fig. 16, the length of bar considerably exceeds the specified limit. There is no choice then, except to use a preliminary operation, as shown, to accumulate the stock into a short cone, the rules governing which will be discussed later. After the second operation, which forges the hex, it is severed from the bar by a punch, which forms the hole the correct size for tapping.

The integral gear segment of the automobile steering gear cross-shaft, Fig. 17, requires less than three diameters of stock. The bar is held on an incline in the dies. The face of the tool is also included so as to drive stock down toward the tip. The second blow forges the gear segment to shape with a flash extending out around the periphery. This flash is trimmed off in the third operation. The section on the right has perfect continuity of grain flow from the shaft into the tips of the gear teeth.

In RULE II repeated applications make it possible to upset great lengths of stock and on each application, the diameter of the preceding upset becomes the diameter of the working stock in the formulae.

Fig. 18, is a good example where 12″ of 1⅛″ stock is gathered into a 3″ diameter upset in four die grooves, each of which is within the diameter limit prescribed. This is .90 carbon tool steel and the ball is later forged into a spade for a pneumatic hammer.

At first glance this method of gathering stock appears to have great possibilities, but in actual practice the possibilities are rather limited.

First, it should be noted that the working stock dare not extend much beyond the mouth of the die, otherwise a ring, or crescent, will be sheared off on the edge of the die by the advancing header. The length of working stock can, therefore, be little longer than the die length of the machine, less the length required for grip.

Second, the stock will normally be hottest on the end, the temperature falling off back toward the grip, which leaves it most resistant to upsetting at the back end of the die impression. This causes it to upset first at the mouth and choke in the die as the heading tool advances. Rapid wear results at the forward end of the die groove, which soon leads to flash forming around the tool face and at the part line of the dies before the base of the upset fills. Flash will be pounded into the next operation, causing objectionable defects.

This choking condition is benefited only slightly if the impression is given a taper, enlarging toward the grip. Better results will be had by reversing the normal gradation of temperature, having it hottest toward the grip, so it will upset there first, and coldest toward the header. This is accomplished by special bricking in the furnace, or by cooling the end of the stock with water just before upsetting.

Round stock, when first acted upon by the heading tool, spirals or

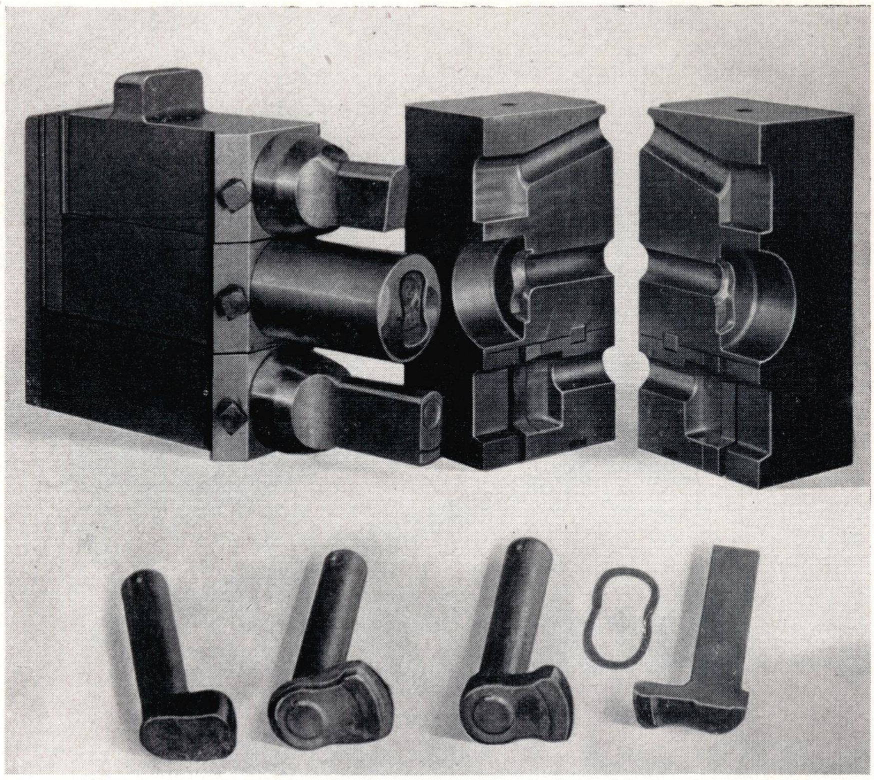
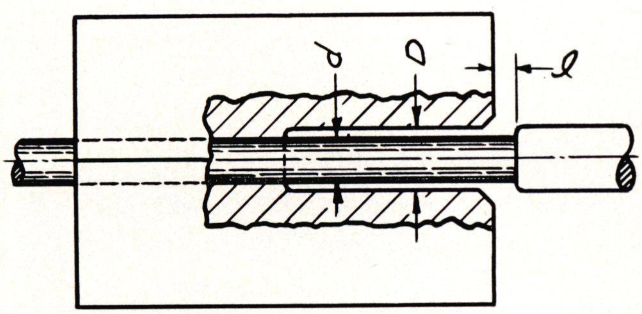


Fig. 17. Automobile steering gear segment cross-shaft.

STOCK SUPPORTED IN DIE IMPRESSION - ONE BLOW



RULE II. WORKING STOCK LONGER THAN THREE DIAMETERS WILL BE SUPPORTED AGAINST INJURIOUS BENDING BY A DIE IMPRESSION OF A DIAMETER NOT GREATER THAN $1\frac{1}{2}$ TIMES THE DIAMETER OF WORKING STOCK, BUT THE LENGTH OF STOCK PROJECTING BEYOND THE IMPRESSION SHOULD NOT EXCEED $\frac{1}{2}$ THE DIAMETER.

WORKING RECOMMENDATION

D SHOULD NOT EXCEED $1.4 \times d$ $\qquad$ l SHOULD NOT EXCEED $D - d$

REPEATED APPLICATIONS OF RULE II MAKE IT POSSIBLE TO UPSET GREAT LENGTHS OF STOCK AND ON EACH APPLICATION THE DIAMETER OF THE PRECEEDING UPSET BECOMES THE DIAMETER OF THE WORKING STOCK IN THE FORMULAE.

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RULE II

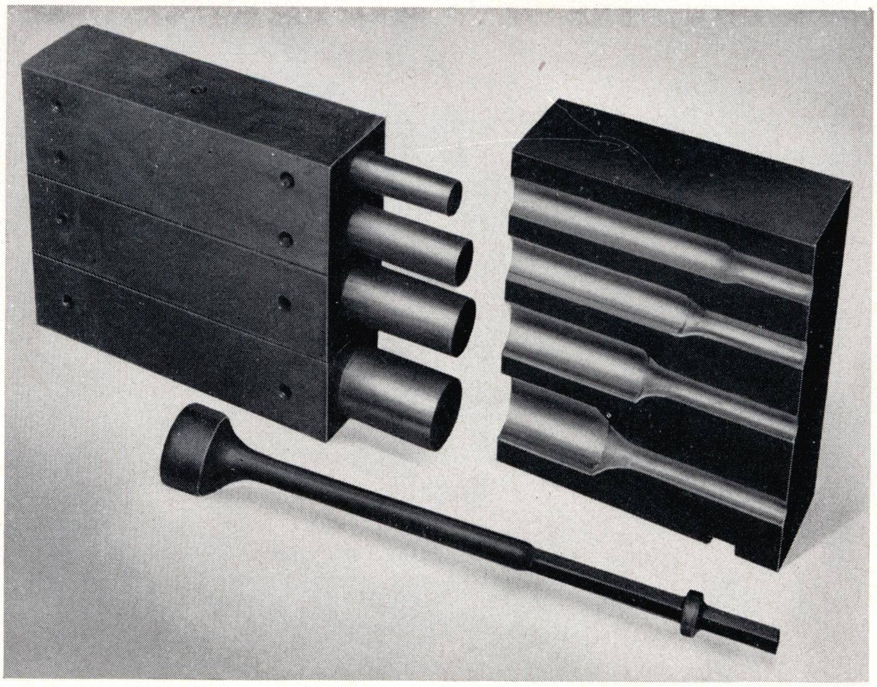


Fig. 18. 12″ of $1\frac{1}{8}$″ stock gathered into a 3″ diameter.

"cork-screws" around the supporting cylindrical die cavity. A considerable part of the wall friction can be eliminated if the cavity is made square, so that the stock will zigzag between diagonal corners. The square upset has less tendency to spiral than to bend back and forth on its short axis, even when upset in a round groove. This behavior is taken advantage of to a limited extent by some use of alternate square and round die impressions, but the advantages gained are considerably offset by the increased difficulties of making the dies and maintaining a good fit between the tool and the die impression.

An interesting departure from the usual groove upsets will be seen in the die, Fig. 19, for forging a freight car brake hanger eye. The tip of the heated stock is cooled before placing in the die, where it extends slightly out of the groove for gauging. The heading tool forces the stock back through the die groove into a

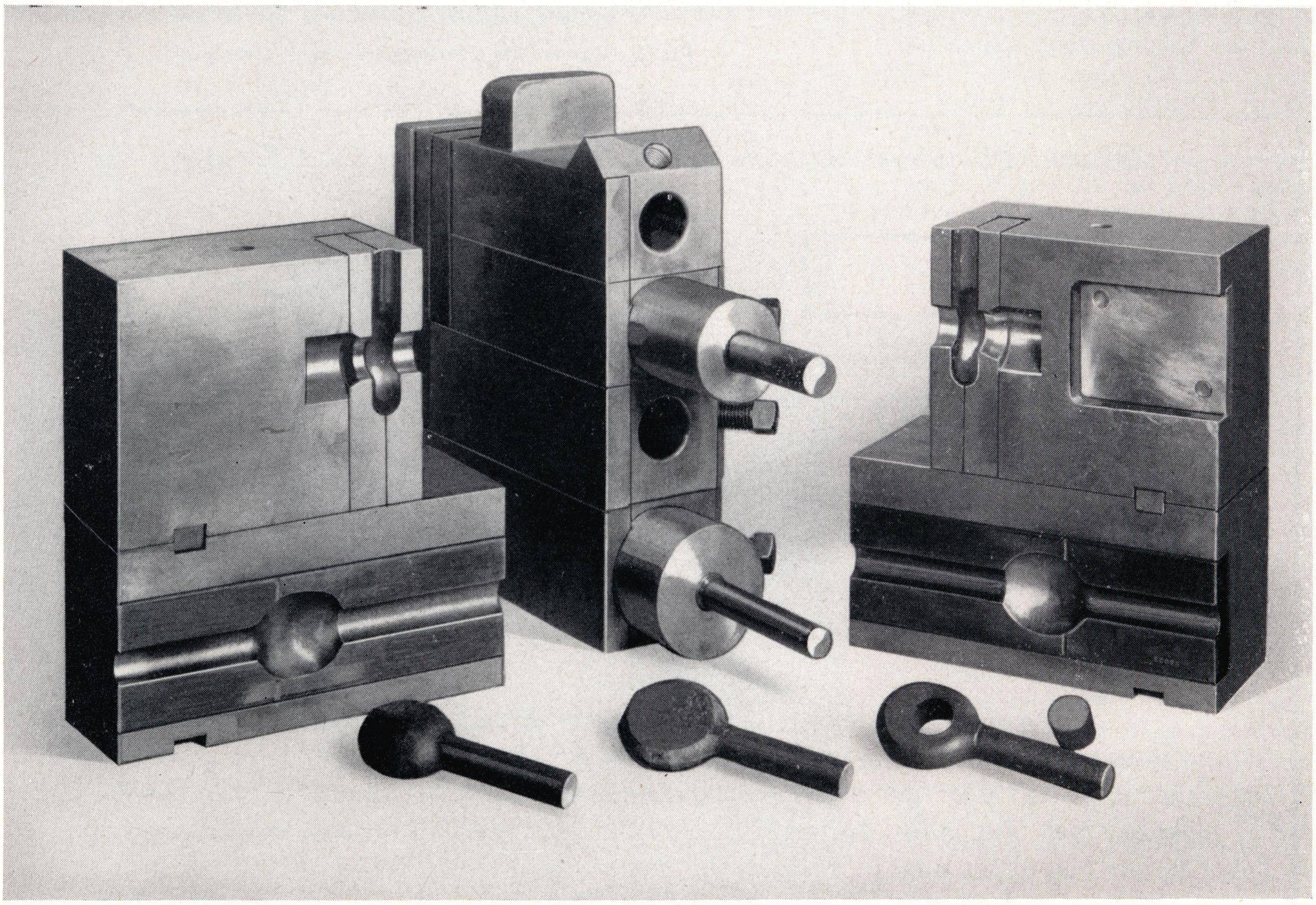


Fig. 19. Dies for forging freight car brake hanger eye.

spherical cavity of a diameter slightly less than three times the diameter of the stock.

The ball of stock is squeezed flat in the upper rear die position, then transferred to the impression at the front where it is held vertically while the hole is punched. The flash which forms at the end of the eye after the die has developed wear, is easily removed by rough handling, or snagging. The producers claim the die and tool maintenance, which is rather high, is more than paid for by the greater hourly production.

An upset can be made in the middle of a bar by using dies and tools similar to the bottom position Fig. 19. In this case the center of the bar is given a localized heat, the two ends remaining cold. One end is gripped and the other cold end is forced back through a groove in the die serving exactly the same function as the tool in the brake hanger die. In this instance there is no flash formed whatsoever.

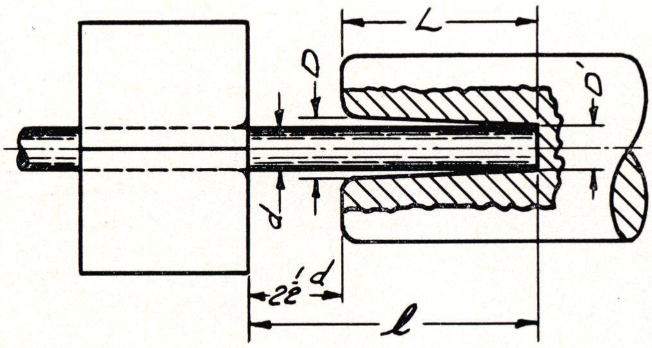
RULE III, covers the gathering of stock in recessed heading tools, the recesses being in the shape of the frustum of a cone, are usually referred to as "cones".

Gathering in cone headers has come to be used on the vast majority of forging operations where a considerable amount of stock must be gathered, but lack of understanding of its sound application and limitations, has been a stumbling block to the inexperienced.

In practical applications of RULE III, the diameter at the mouth of the tool should not be greater than 1.4 times the diameter of the stock. The diameter at the bottom of the recess should not be greater than 1.1 times the diameter of the stock. The recess should be long enough to accommodate ⅔rds of the length of the working stock, as normally, bending will take place at the middle first. The length of stock exposed between the dies and the tool when upsetting starts should not be greater than 2½ diameters, but this can be slightly increased if the stock is heated hottest at the end, graduating to a lower forging temperature at the grip.

Repeated applications of Rule III make it possible to upset very great lengths of stock and on each application, the average diameter of the preceding upset becomes the diameter of the working stock in the formulae.

STOCK SUPPORTED IN TOOL RECESS – ONE BLOW



RULE III. WORKING STOCK LONGER THAN THREE DIAMETERS WILL BE SUPPORTED AGAINST INJURIOUS BENDING BY A HEADING TOOL RECESS OF A DIAMETER NOT GREATER THAN $1\frac{1}{2}$ TIMES THE DIAMETER OF WORKING STOCK AT THE MOUTH AND $1\frac{1}{8}$ TIMES THE DIAMETER OF WORKING STOCK AT THE BOTTOM AND A LENGTH OF RECESS NOT LESS THAN $\frac{2}{3}$RDS THE LENGTH OF THE WORKING STOCK OR NOT LESS THAN THE LENGTH OF WORKING STOCK MINUS $2\frac{1}{2}$ TIMES ITS DIAMETER.

WORKING RECOMMENDATION

D' SHOULD NOT EXCEED $1\frac{1}{8} \times d$ L' SHOULD NOT EXCEED $2\frac{1}{2} \times d$

D SHOULD NOT EXCEED $1.4 \times d$ L SHOULD NOT BE LESS THAN $\frac{2}{3} l$

REPEATED APPLICATIONS OF RULE III MAKE IT POSSIBLE TO UPSET VERY GREAT LENGTHS OF STOCK AND ON EACH APPLICATION THE AVERAGE DIAMETER OF THE PRECEEDING UPSET BECOMES THE DIAMETER OF THE WORKING STOCK IN THE FORMULAE.

THE LENGTH OF EXPOSED STOCK $2\frac{1}{2}d$, CAN BE SLIGHTLY INCREASED IF THE STOCK IS HEATED HOTTEST AT THE END AND GRADUATED TO A LOWER FORGING TEMPERATURE AT THE GRIP.

PREFERENCE IS GIVEN TO RECESSED HEADING TOOLS, OWING TO THEIR DURABILITY AND BECAUSE THE UPSETS ARE FREE FROM THE FLASH PLUNGER-LIKE HEADING TOOLS TEND TO FORM AT THE DIE PART LINE AND AROUND THEIR PERIPHERY WHEN UPSETTING IN GROOVES IN THE DIE.

AJAX MFG. CO.

RULE III

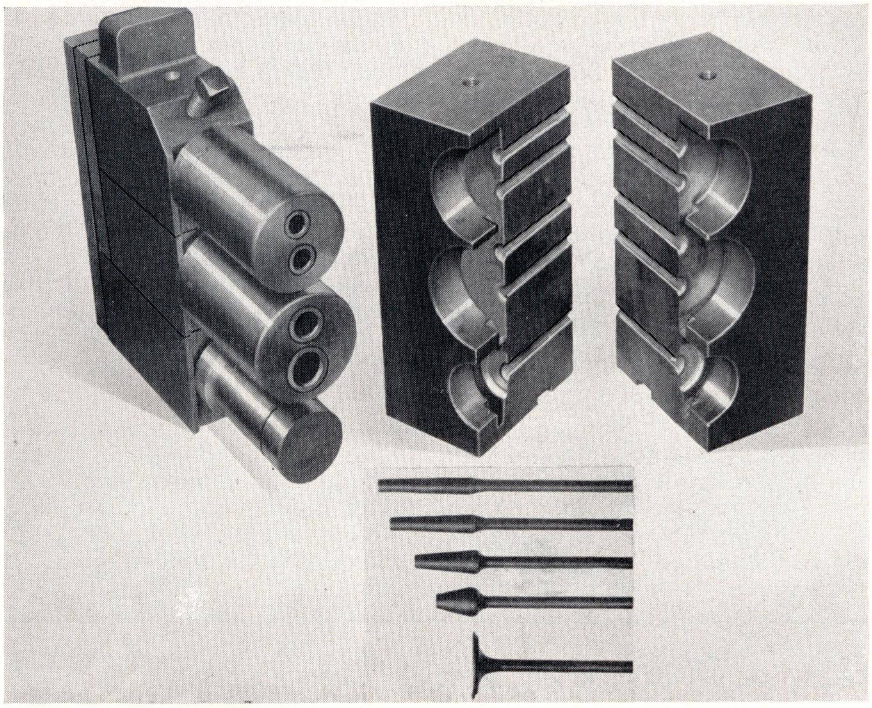


Fig. 20. At left, gathering 4″ of $\frac{5}{16}$″ stock into a $1\frac{3}{8}$″ valve head.

Mechanical considerations are practically all in favor of this type of tooling, as against gathering in impressions in the dies.

The working stock can extend far beyond the die length of the machine, frequently even projecting up into the toolholder.

Stock heated in a box type furnace, with slot opening, normally is hottest at the end, causing an ideal sequence in upsetting. It fills the dead end of the cavity first, progressively upsetting toward the mouth, while the gap between the gripper dies and the header is decreasing.

Recessed headers are cheap to make and are extremely durable. The cost can be decreased further and durability increased by inserting high grade bushings around the recess and renewable pins at the dead end. These pins provide a convenient means of compensating for wear and maintaining volumetric balance between cones.

This has been done in the headers for producing automobile valves, Fig 20. They gather 4″ of $\frac{5}{16}$″ stock into a $1\frac{3}{8}$″ valve head in five operations, and it is interesting to note that the amount of gather in each of the four cones follows RULE III. This is cold drawn, heat resisting alloy steel on which scaling is negligible.

One of the disadvantages of cone headers ordinarily is that scale accumulates and plugs the bottom of the cavities, thereby changing their volume and causing flash to form at the face of the tool. To overcome this, vent holes are provided at the end, preferably running out to the side of the tool. If a slight amount of cooling water is introduced through these vent holes, the steam generated when the hot stock contacts it, will blast the scale out as it is loosened from the bar at the start of upsetting. Compressed air is sometimes connected into these vent holes by flexible hose so as to blow the scale out during and after each operation, before it becomes lodged.

This latter method is employed on the hollow headers for upsetting oil well sucker rod ends, Fig. 21.

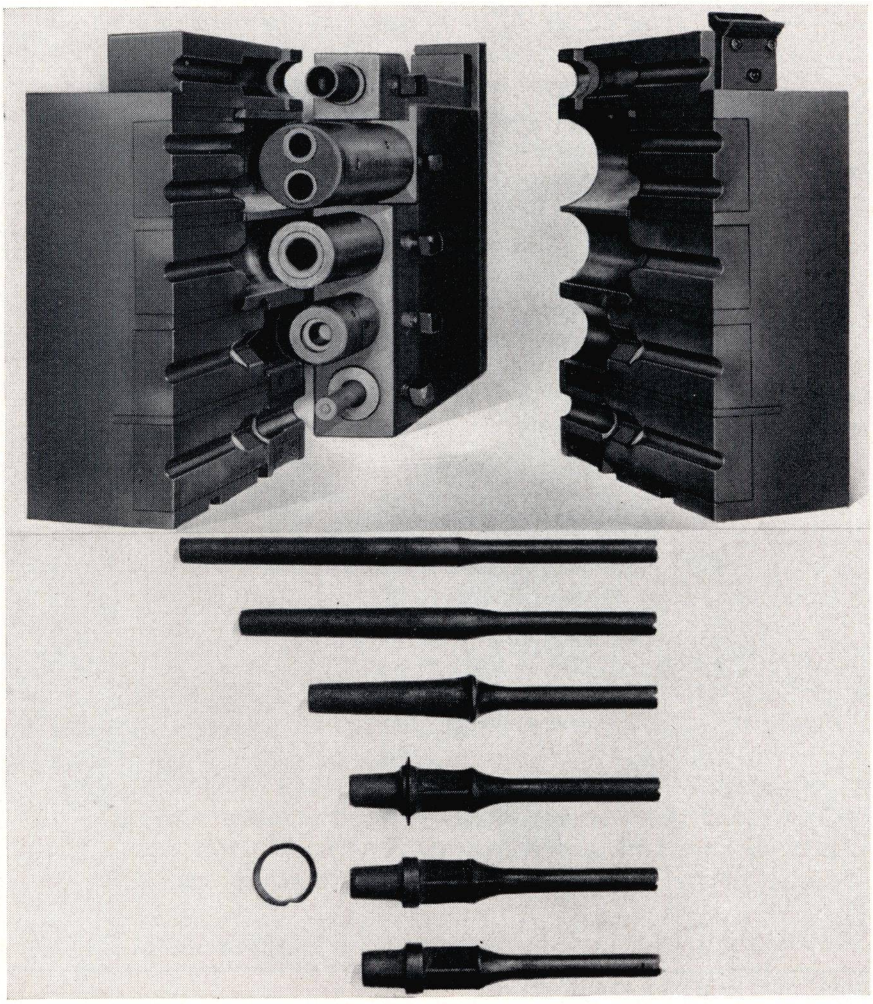


Fig. 21. At left, pin end sucker rod dies with cone tools.

Here again RULE III is applied.

After four upsetting operations in hollow headers, the piece is transferred to the top impression for trimming the washer shaped flash, formed when the square is filled in the fourth operation. From there it is moved down to the bottom impression where it is rotated and struck repeatedly to square up the wrench-hold while the pin end undergoes additional upsetting to secure maximum working and strength, as that section, which is later threaded, is subjected to considerable fatigue during pumping.

In addition to insert bushings around the tool impressions, there are rectangular inserts in the gripper dies, which can be renewed with little expense.

Another disadvantage of the hollow headers which comes up in these rod dies, is the difficulty of gauging stock when it projects into the headers and makes use of the swinging stock gauge impossible.

In this case the twenty foot bars are chalk marked before heating and the operator brings this mark in line with a gauge bar bolted in the machine feed gap.

Shorter, uniform length blanks can be gauged with a backstop, or collar tongs, but where the bars are long, either visual gauging, or offset or goose-neck tongs butting against the back of the die, are used. Correct gauging is of importance, as all cones must be filled perfectly. An underfill at the mouth of the header, which is the last location to fill, being exposed on the next operation, may cause the stock to fold or corkscrew in front of the header, forming a flash and making a scrap forging.

The sliding dies, Fig. 22, which are in reality a modified form of hollow headers, fall under Rule III and have the advantage of easy gauging against the end of the impression. Also they are not subject to packing with scale, as it falls out when the dies open and the slide blocks are pushed to the forward position by springs.

The greater facility of gauging is reflected by increased production over that obtained from the hollow headers, when the dies are operating satisfactorily. However, sliding dies are rather hard to maintain, as the guide surfaces are subjected to terrific pressure, accumulate highly abrasive scale, and are difficult to lubricate, since the slide blocks themselves pick up considerable heat, frequently enough to draw the temper from the springs. These troubles and their greater expense, offset most of their advantages.

Sliding dies do have the ability to upset stock in a second location simultaneously with upsetting at the end.

Automobile cluster gear dies, Fig. 23, are a good example. The small gear at the rear is upset at the same

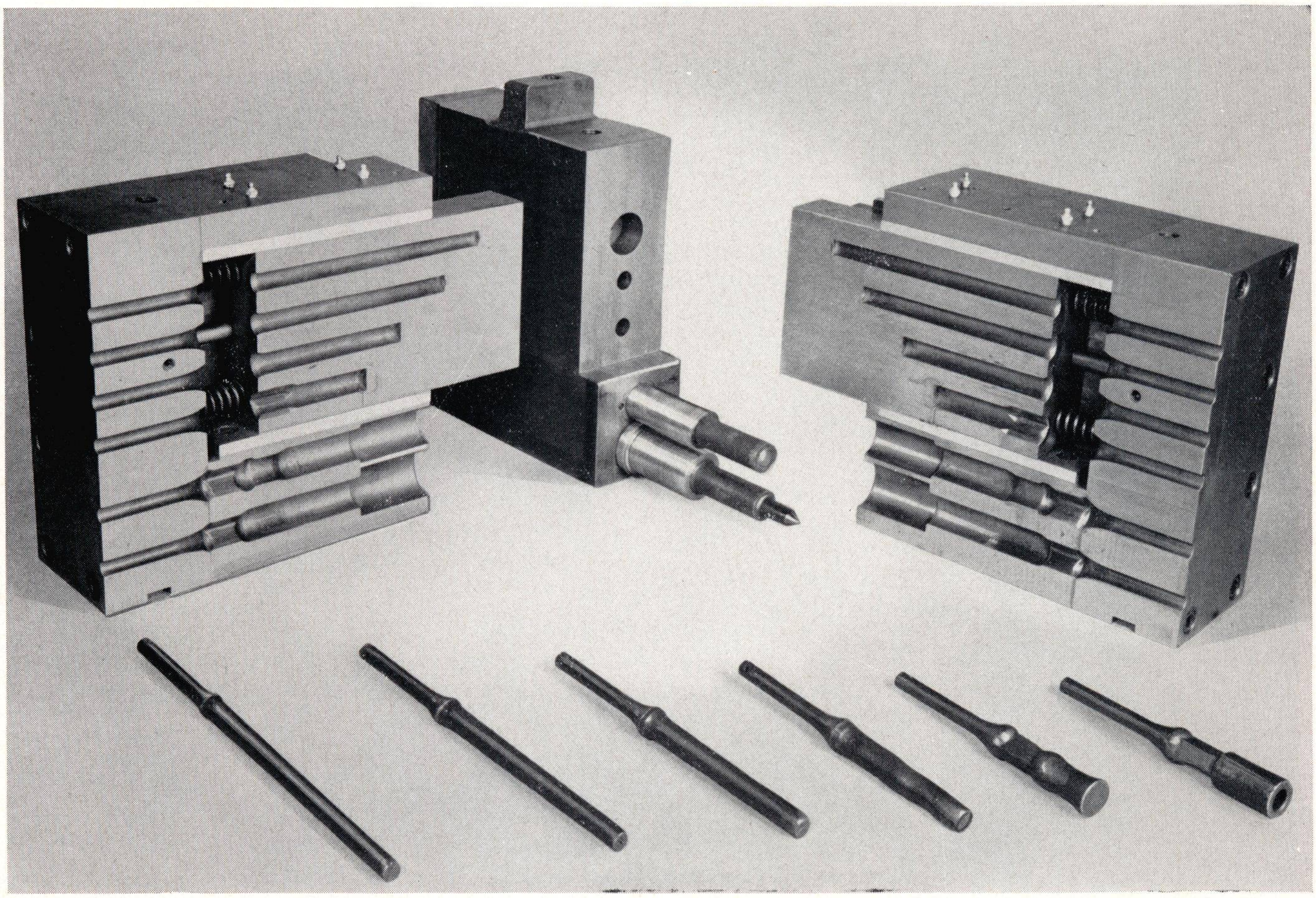


Fig. 22. Sliding dies—a modified form of hollow headers.

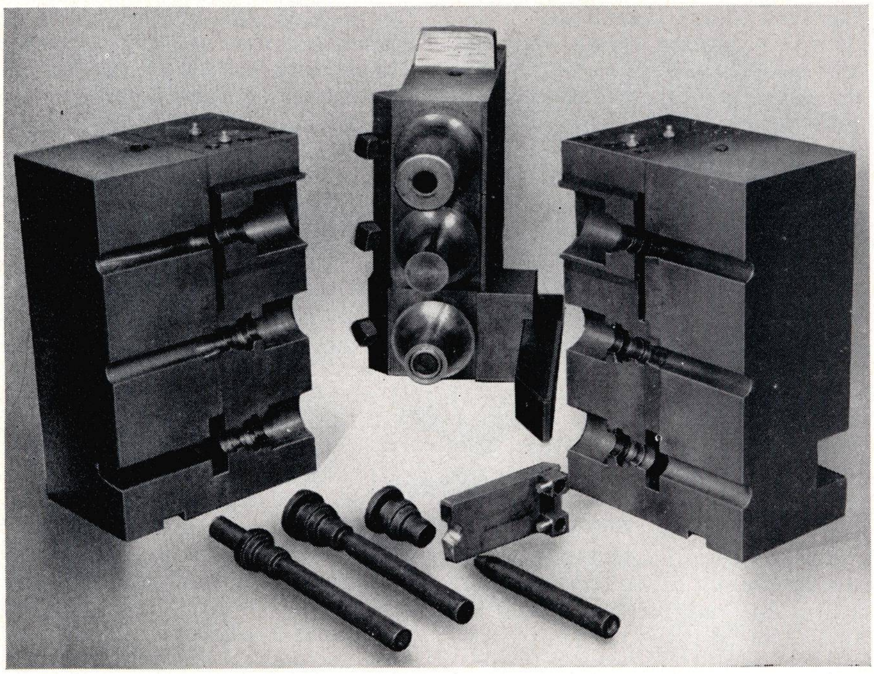


Fig. 23. Sliding dies for upsetting automobile cluster gears.

time as the preliminary cone. Another interesting feature of these dies is the cutoff in the last operation in the stationary die, which is actuated by a wedge at the side of the toolholder. The forging being entirely confined before the shear blade acts, is not distorted as it might be if the shearing were done by the moving die in closing.

The radial engine planetary gear forging, Fig. 24, is interesting from the standpoint of differentiating between "working stock" and stock which does not undergo a change in shape during a heading operation. The rather long cone formed in the first hollow header, projects up into a close fitting impression for about half its length in the second header. This leaves considerably less than 2½ diameters to be forged into a funnel-shaped recess in the second operation die. In the third operation the grip is relieved so that a drawing action takes place. After final forging

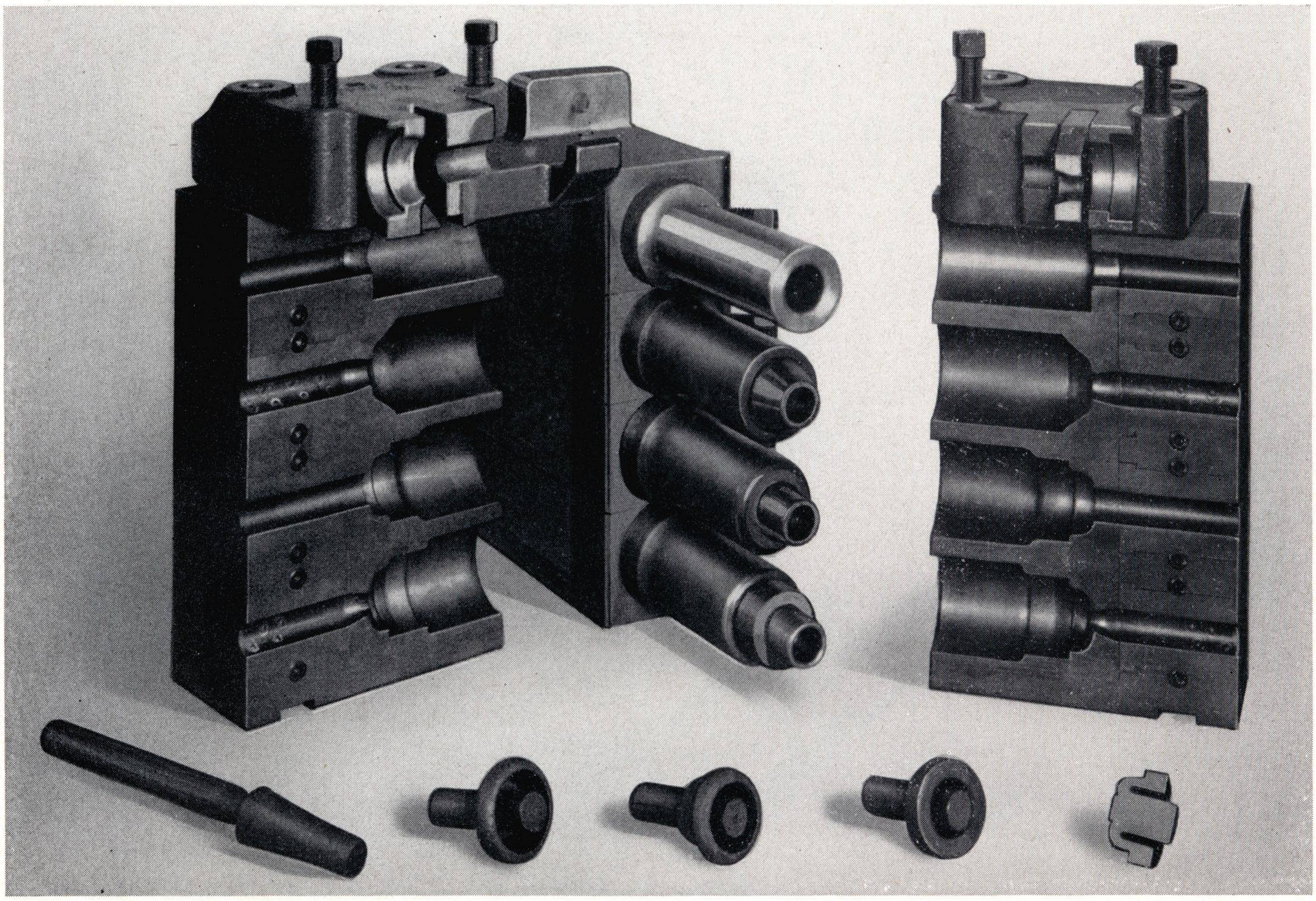


Fig. 24. Dies for radial engine planetary gear forging.

in the bottom impression, the piece is transferred to shear blades in the die clamps, which severe it from the bar, where it had been necked down by the dies during the preceding operations.

In forging a spoke foot, Fig. 25, two cone tools gather the stock concentric. Then, in order to fill out the extremities of the ears, it is flattened between the dies before the third upsetting operation. In the bottom position a spring supported trimmer removes the flash, and simultaneously two punches punch the holes for the rivets.

In forging a roller-type steering gear cross-shaft, Fig. 26, the first stock gather is made in a cone tool; the second gather, because of its unsymmetrical shape, is made in a groove in the dies. The piece is then held vertically in the next impression, with the end of the blank rigidly backstopped at the top of the die, while the recessing tool is driven in

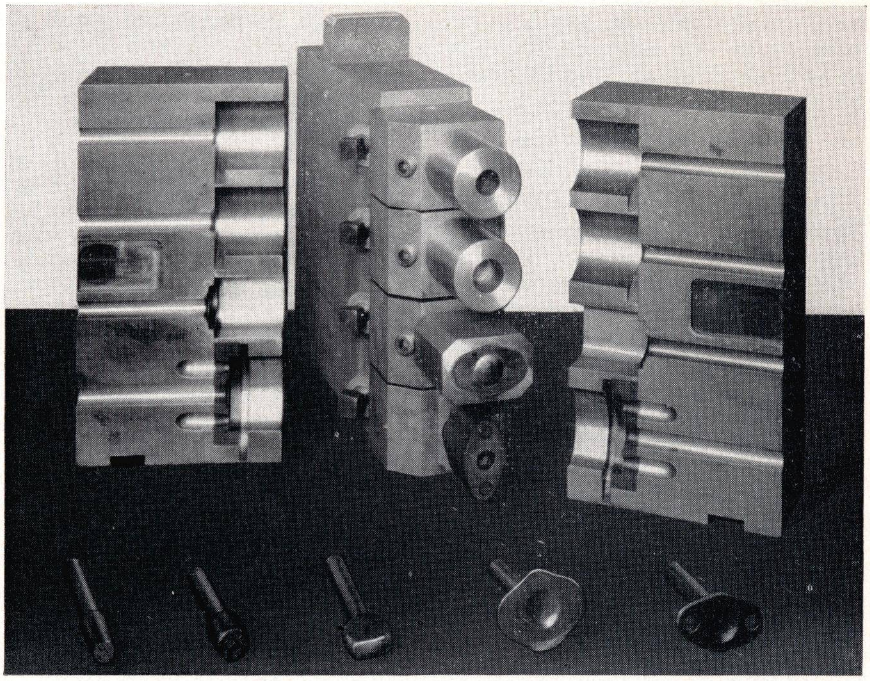


Fig. 25. Dies for forging a spoke foot.

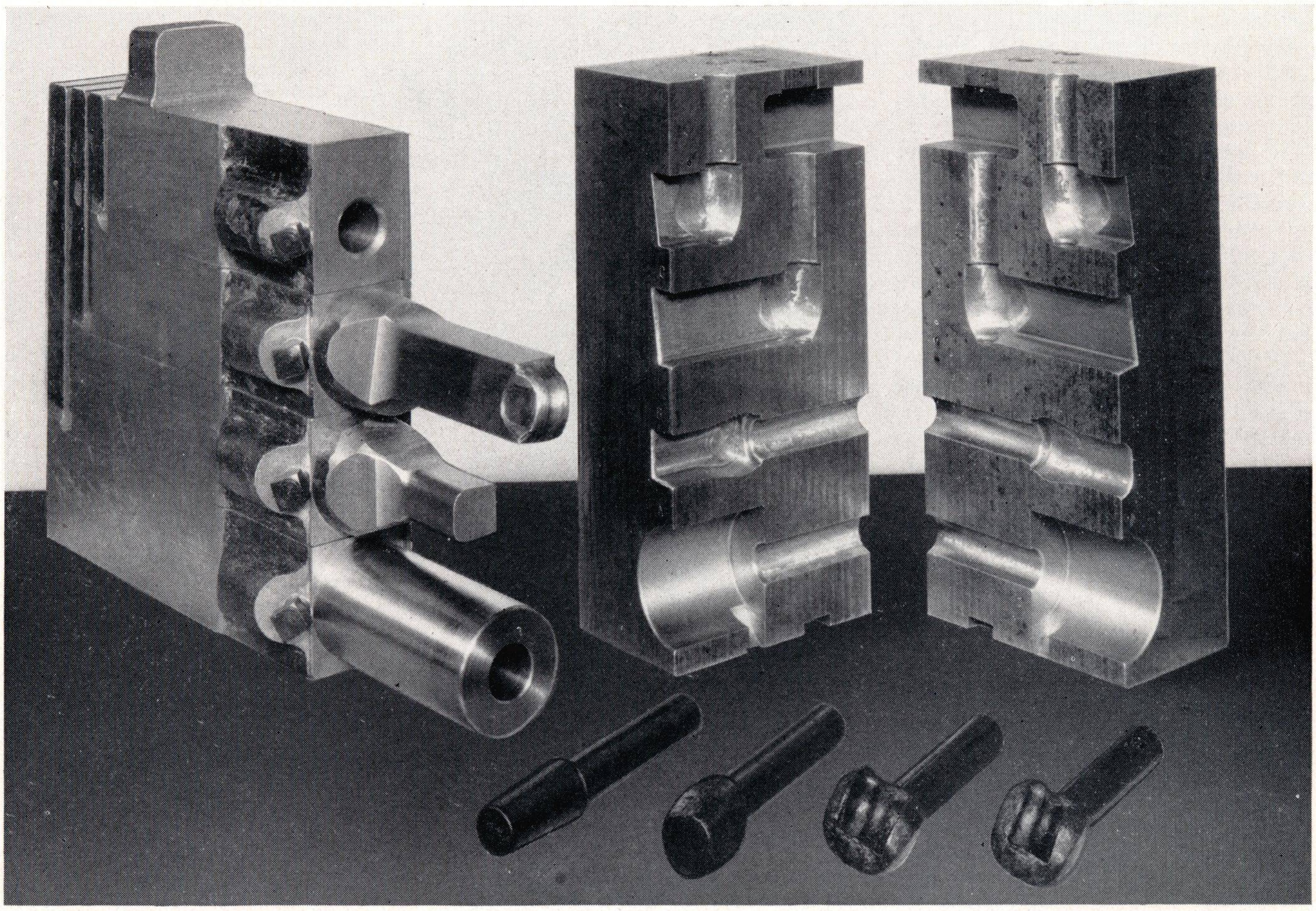


Fig. 26. Dies for forging a roller type steering gear cross-shaft.

to form the ears. In the top impression the dies squeeze the ears in so as to eliminate draft in the space between them.

Progressive Piercing or Internal Displacement

Progressive piercing, or internal displacement, is the process widely employed on Upsetting Forging Machines for producing tubular, or hollow cylindrical forgings, either with holes extending all the way through, such as radial engine cylinders; with a closed end, such as artillery shell forgings; or as enlarged hollow cylindrical ends on solid bars.

Vast quantities of artillery shell forgings, particularly up to and including the 105 mm, were produced on Upsetters by this method during the past war, successfully competing with the older hydraulic press method of piercing and drawing. The fundamental difference between progressive piercing and ordinary piercing will be understood best by comparison of the two methods of forging shells.

On a hydraulic press, a short blank with cross-sectional dimensions approximating the diameter of the die is centered and bottomed in a cylindrical die impression. A piercer of the diameter of the shell cavity is forced into the blank. As the piercer advances, it develops hydrostatic-like pressure within the metal of the blank, forcing it to extrude, or counter-flow, back along the piercer between it and the walls of the die. The pierced blank is then drawn to length by pushing through draw rings or rollers by means of a mandrel.

The progressive piercing method as performed in Upsetting Forging Machines in the dies illustrated, Fig. 27, will be understood by referring to the sketch in the foreground. This shows the stock positioned in each impression ready to be acted upon by the header or piercer. Bar stock of small enough cross-section is selected so that after initially upsetting the end to the outside diameter of the shell with an additional small end collar, the length is equal to the length of the shell. This blank is then placed in a die impression, bored at the back to grip the stock, and bored at the mouth to grip and center the upset end, and this large bore extended back a sufficient distance to accommodate metal displaced by the piercer. It will be noted that the stock is unsupported in this cavity for a length approximating the length to be pierced.

After the first piercing, the blank is transferred to the next position, where it is again gripped at the back and the pierced section gripped and centered in an impression, which again leaves the stock unsupported for the length to be displaced by the second piercer. This procedure is repeated in the next die impression, where the third longer piercer penetrates to practically full depth. In the next position, the end collar is trimmed off by the short trimming punch. In the bottom impression, the final piercer simply sizes the shell cavity. The length of blank has remained unchanged since the initial centering upset.

It is of the utmost importance that the length of the blank is not changed during progressive piercing. Should the blank be driven back into the base of the die cavity, the piercer in bottoming, will either counter-flow the metal to re-establish length, causing increased die wear, or worse still, will extrude the metal through the grips, in which case the shell forging will be short and scrap.

The end collar, upset in the first operation and supported in grooves in the gripper dies during progressive piercing, does much toward overcoming this trouble, and also facilitates proper locating of the piece in the die impressions.

Tests during actual production showed that for various sizes of shells, the progressive piercers developed pressures in excess of 30,000 p.s.i. of projected area, where the included angle of the nose was approximately 60°. Tests further showed that the long taper of the third piercer, developed 50% higher pressures, indicating that increased friction, caused by the long, gentle

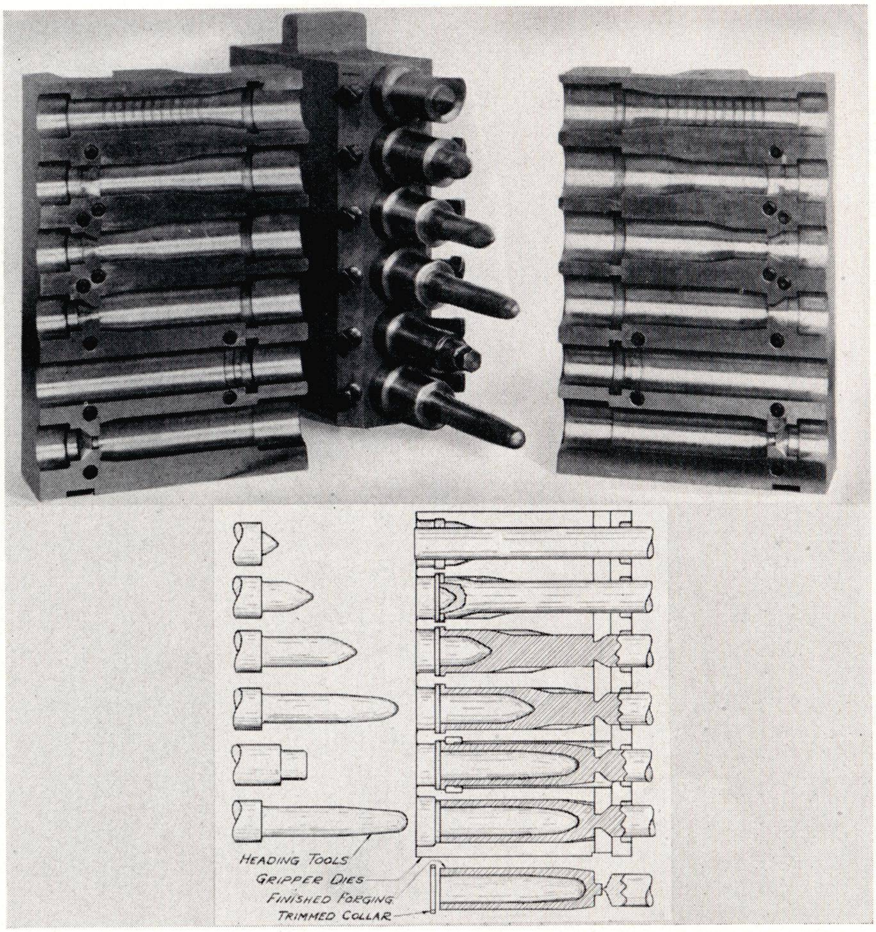


Fig. 27. Shell forging by the progressive piercing method.

taper, is quite a factor. The cavities were forge-finished to a tolerance of $\pm.010''$ and even so the piercer life averaged better than 5,000 shells.

Experience dictates included nose angles of from 60° to 90°. The magnitude of the force, tending to crowd the metal back into the die cavity, must be borne in mind in arriving at die designs to offset this damaging action. The end collar is now very generally added, if the design of the forging does not already have a flange or shoulder to serve a like purpose.

In the case of nitralloy radial engine cylinder forgings, Fig. 28, the flange for securing them to the crankcase serves ideally the purpose of the end collar. Furthermore, the working stock ahead of the piercer is of large diameter and short, so that its stiffness also assists in maintaining length.

Extremely large cylinder barrel forgings weigh more than 100 lbs. each. If made off the end of bars by the method just shown, the weight of bars becomes excessive and they are awkward to handle, even with the help of an overhead crane. To overcome this, blanks sheared to correct length for a single cylinder are used. After heating, a 1″ porter bar is pushed into the end of the blank by a light hydraulic press. In three operations, Fig. 29, the blank is upset and progressively pierced into a heavy bottomed cup about 2″ short of the required length. In the fourth operation, a long, taper-nosed tool expands and stretches the metal at the base into the back of the die cavity, frees the porter bar and shears off a light walled ring, which is the only metal wasted in forging, as against the length for grip and tong hold from the end of each bar by the method previously illustrated.

The aluminum piston forgings, used also in radial aircraft engines, offer another interesting use of the porter bar for considerations other than weight. Long aluminum bars are fed into a turret lathe, where a hole is drilled in the end, and a parting tool cuts off blanks to length. After heating, the blank, Fig. 30, is handled into the upsetter with the shouldered porter bar. During the first upsetting, the shoulder is locked in the dies to prevent movement.

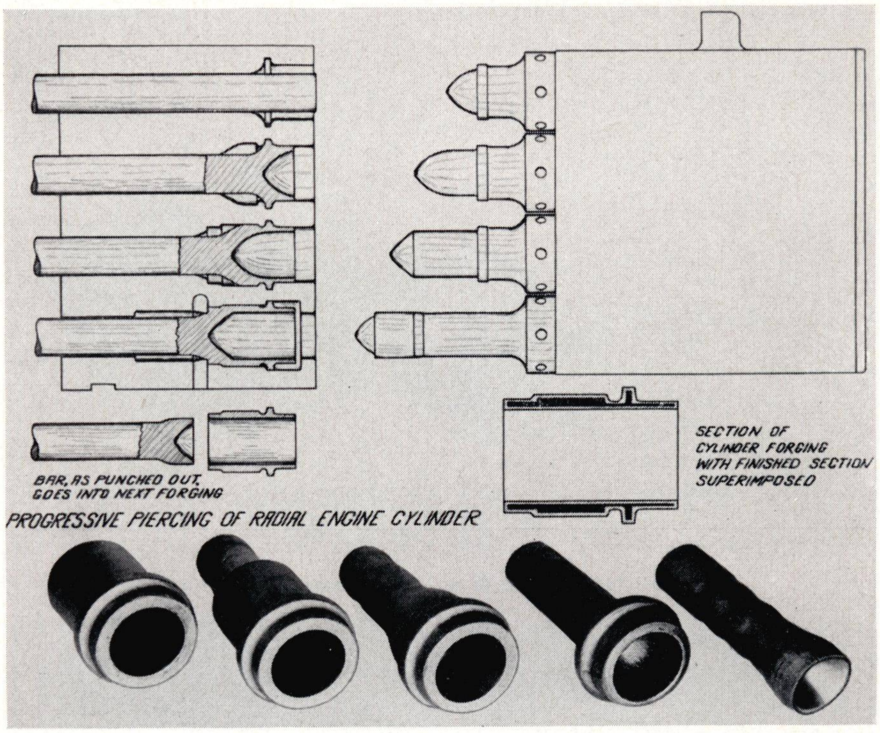


Fig. 28. Nitralloy radial engine cylinder forgings.

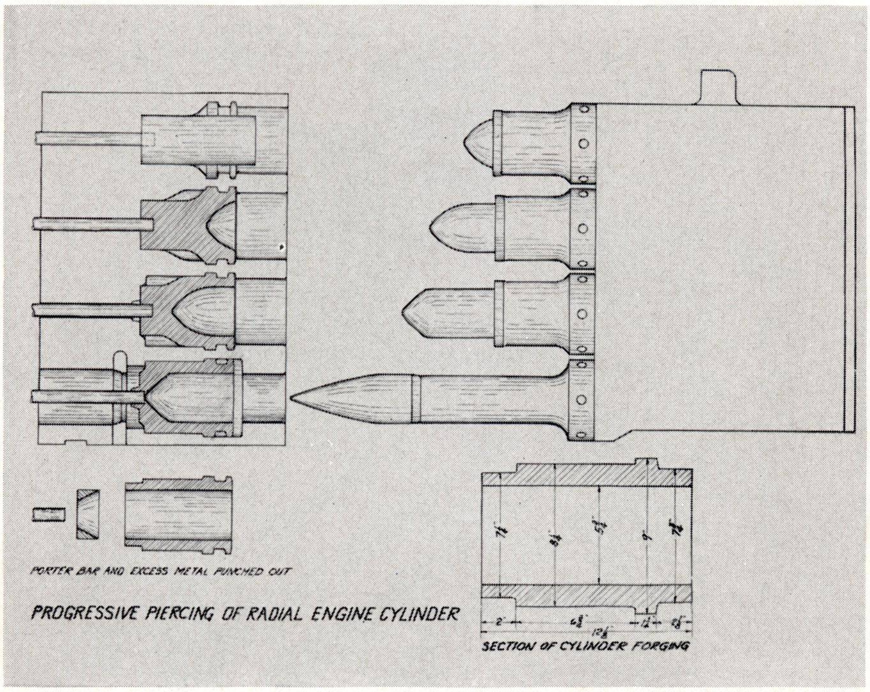


Fig. 29. Upsetting, progressive piercing and shearing off.

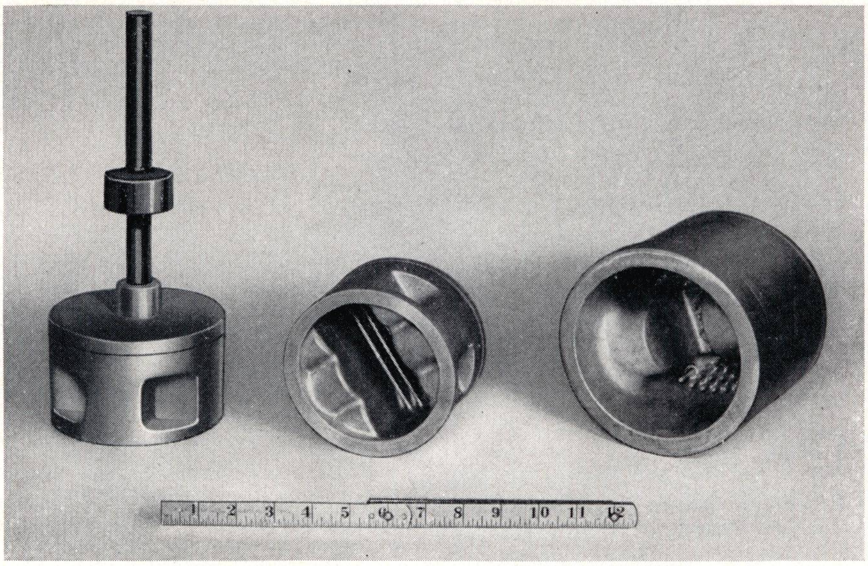


Fig. 30. Porter bar used in forging aluminum pistons.

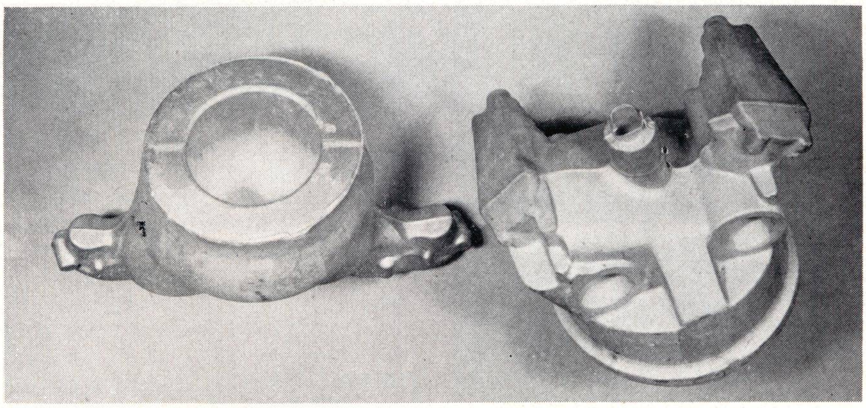


Fig. 31. Forged radial engine cylinder heads.

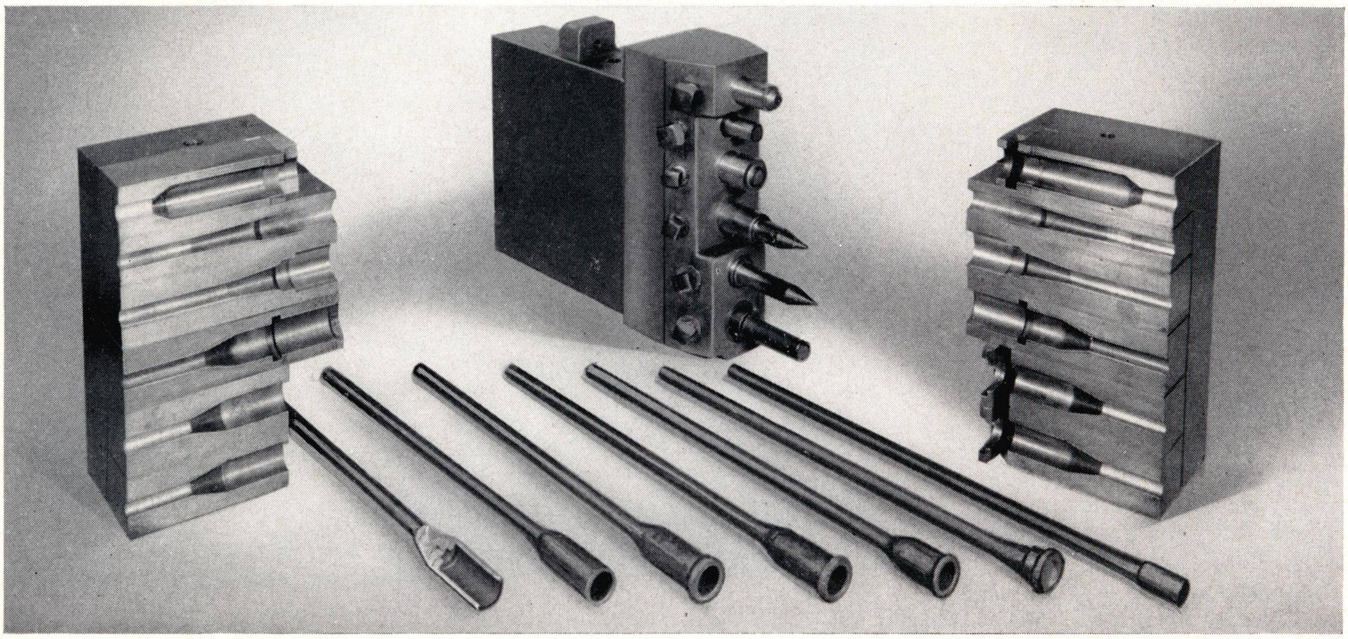
During the second operation, when the internal displacement tool enters, the porter bar is permitted to kick back in the die about an inch, and the box extrudes around its end. During finish forging, the shoulder is not supported and a slight additional extrusion releases the porter bar from the boss, which is later machined off, leaving the top of the piston flat.

Forged radial engine cylinder heads, Fig. 31, although of aluminum, weigh approximately 80 pounds. The handling problem is solved by securing the porter bar in the blank during preliminary forging in a 2500 ton AJAX High Speed Mechanical Forging Press. The metal extrudes out in the die around the porter bar, which is locked in the die. This bar is then used for handling during finish forging in a second 2500 ton press and also during the internal displacement, or "domeing" operation, which is done in an 8″ AJAX Upsetter.

Small Diameter Stock — Large Diameter Piercer:

When the stock is of small diameter in relation to the diameter of the piercer, and the thin wall is capable of little lengthwise support, the depth of pierce in a single operation is limited by the diameter of stock. As shown earlier, the stock is

Fig. 32. Dies for forging automobile steering gear drag link.



unsupported in the die cavity for a length about equal to the depth of pierce. When the piercer delivers excessive pressure, the end collar may shear off or suck into the die groove, or the thin walls may stretch. If the working stock is unsupported for a length as great as three times its diameter, it may buckle to one side, leading the punch off and causing in addition an eccentric forging.

This three diameters cannot be treated as a definite limit, as with a sturdy end collar the extremely light wall may cool so rapidly that it causes resistance to stretching or slipping back in the die,

In the case of the automobile steering gear drag link, Fig. 32, where the amount of unsupported working stock is slightly greater than three diameters, there is very little trouble. The stock for that forging is 9/16″ round, the piercer diameter 1″, and the depth of cavity 3½″. The comparatively low pressure on the piercers is reflected by an average life of from 10,000 to 15,000 pieces, against a 5,000 average on the artillery shells.

The dies, Fig. 33, are for the female half of a Navy anchor chain link. The blank is 3″ round bent into a "U". It is handled into the dies by tongs which fit the small clearance groove at the back of the impressions. The ends of the U-blank extend forward into the guide portions of the top impression and are perfectly centered when acted upon by the preliminary piercers. These are rather blunt and pack the stock into the impressions, extruding the spacer lugs or "stud" and counter-flowing the stock up around the punches.

The second pair of punches are of the spreading or internal displacement type.

To complete this link the tapered, corrugated, gimlet-like points of a mating staple are locked into the sockets by forging the metal into the corrugations in a large steam hammer.

Small Piercer — Large Stock:

Where the working stock is of large cross-section in comparison to the piercer, and the wall thickness correspondingly great, the problem of maintaining length is not so acute. The thicker walls have more resistance to spreading by the piercer, unit pressures on the piercer are higher at the same time the piercer has less body and greater surface area, so it is generally piercer life which determines the number of operations to achieve the desired depth.

The automotive universal joint housing Fig. 34, falls in this classification and is one of the earliest deep pierced jobs with which we are familiar, having been developed over twenty years ago.

In the first impression, Fig. 34, 2½″ of the 2½″ stock extends unsupported out from the grips. A conical tool, with a 1⅜″ diameter nose, drives into this stock belling it out into a funnel shape and dis-

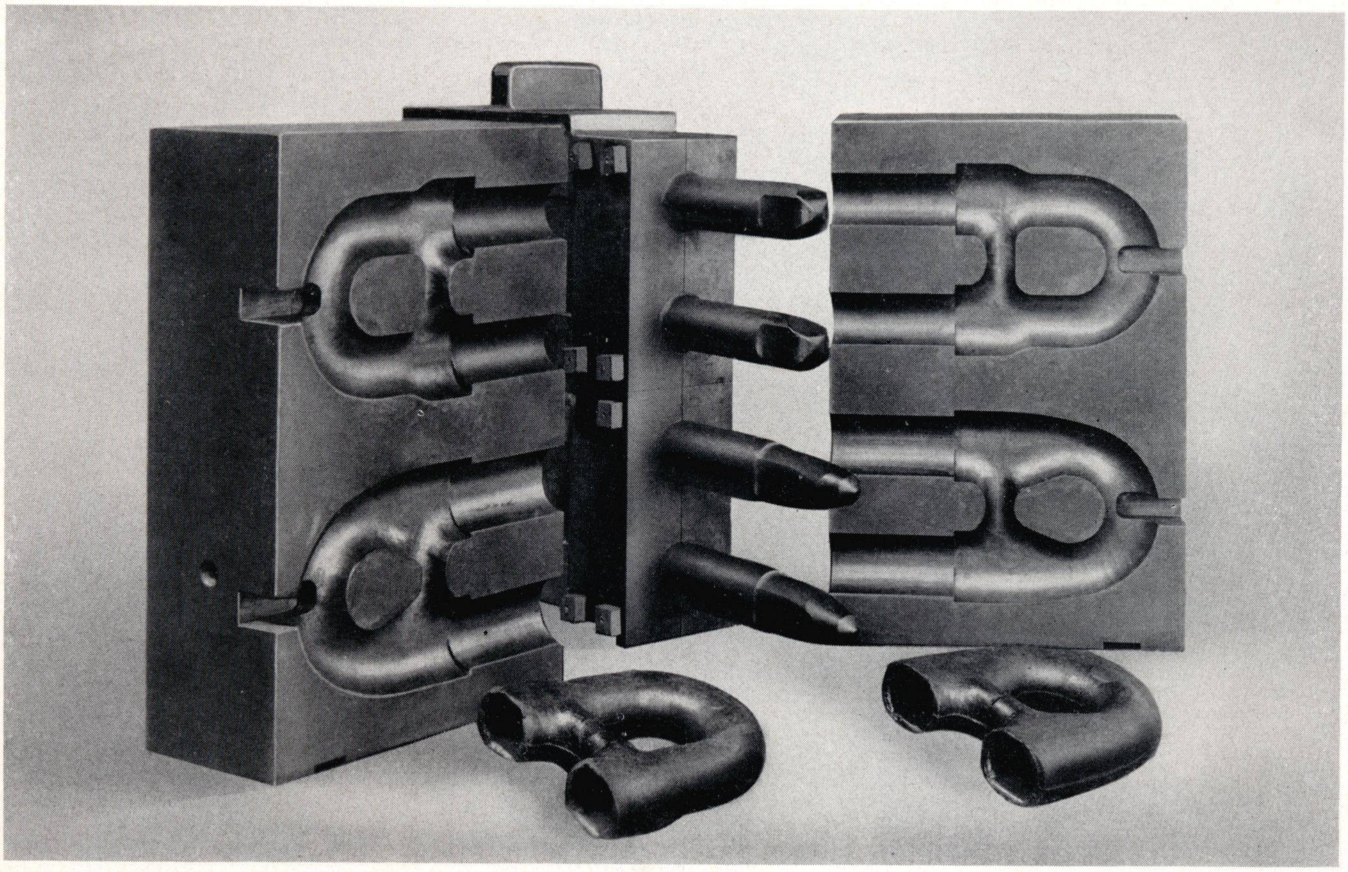


Fig. 33. Dies for half of navy anchor chain link.

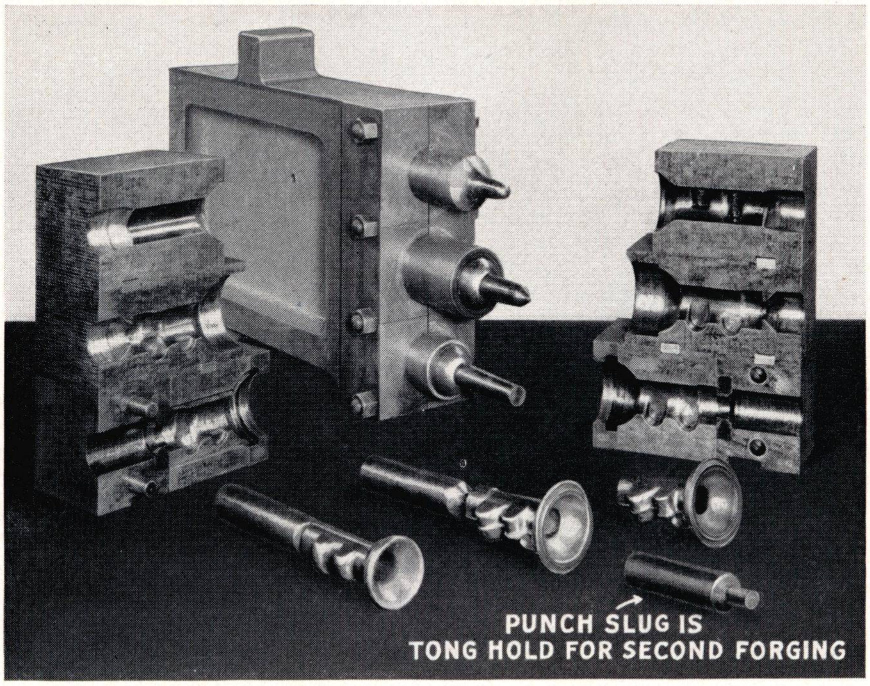


Fig. 34. Dies for deep pierced universal joint housing.

placing metal into the two side bosses. Knicker plates hold the bar from sliding back through the very short grip. The second tool drives a longer displacement punch well into the forging, fills the bosses up sharp and forms the spherical end cup. The third flat nosed tool punches on through and sizes the hole.

The other half of the double-length blank is handled by the punch slug while producing the second forging, solving the problem of disposing of a bad bar end.

The drive shaft flange, Fig. 35, requires a preliminary cone stock gathering operation. The rectangular flange and four bolt bosses are next upset to shape, leaving the hub undersize. A displacement punch is next driven practically through, expanding the hub to full diameter. Punching leaves a small diameter slug on the end of the bar, which is cut off in the inserted shear plates at the back of the dies before the

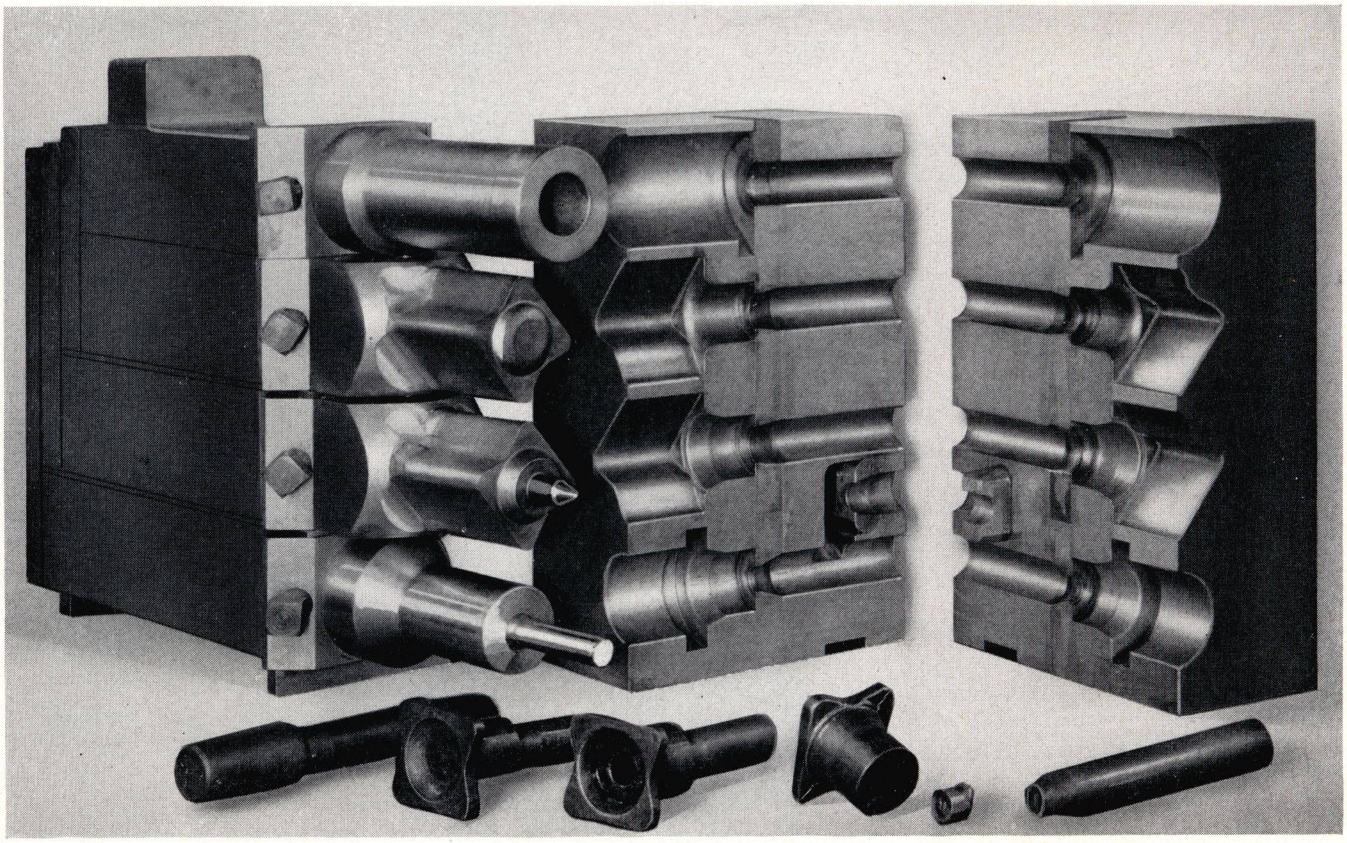


Fig. 35. Dies for drive shaft flange.

bar is returned to the furnace for heating.

In the clustered gear, Fig. 36, a 1″ diameter hole is pierced for a length of 5″ by only two piercers.

Starting at the bottom, a sliding die and a hollow header simultaneously gather stock for the two end gears. A second operation, performed in a double sliding die, further upsets the gear at the rear and gathers stock for the middle enlargement, while the heading tool completes the upsetting of the end gear and forms a shallow centering hole. In the third operation, the 1″ piercer penetrates 2½″, filling the center enlargement to full dimensions. The final piercer, which is also pointed, penetrates a like distance, filling the back gear out to full size, traveling on through the punch plate and severing the forging from the bar.

The punch slug is sheared from the end of the bar in the eye type shear blade located at the back of the stationary die, about half way up, before it is returned to the furnace for reheating. When the bar is reduced to a length where only one more forging can be made, this shearing operation is omitted. The opposite end of the blank is heated and the punch slug serves as a tong hold while forging the final piece, thus reducing the crop end from each bar to the very small spool shown in the foreground. Fig. 36.

The holes are sufficiently accurate to finish by broaching and with proper die setting, have excellent concentricity, which no doubt, is helped by the punch slug leading the piercer through the hole in the punch plate in the last operation. Piercer life is reported as averaging between 2500 and 3000 gear blanks.

Some clustered gears of greater length, with deep pierced holes, are forged from both ends, using two forging machines operating in conjunction. Such is the case with this gear 7″ long, with 1$\frac{1}{32}$″ hole pierced all the way through.

In the dies, Fig. 37, in the first machine, the pre-sheared blank is handled with a socket porter bar shouldered into the die impressions. The first operation in a hollow header gathers stock at the center; the second header gathers stock for the end gear. The third tool completes the upsetting of the end gear and forms a shallow center. A 1$\frac{1}{32}$″ displacement piercer, in the

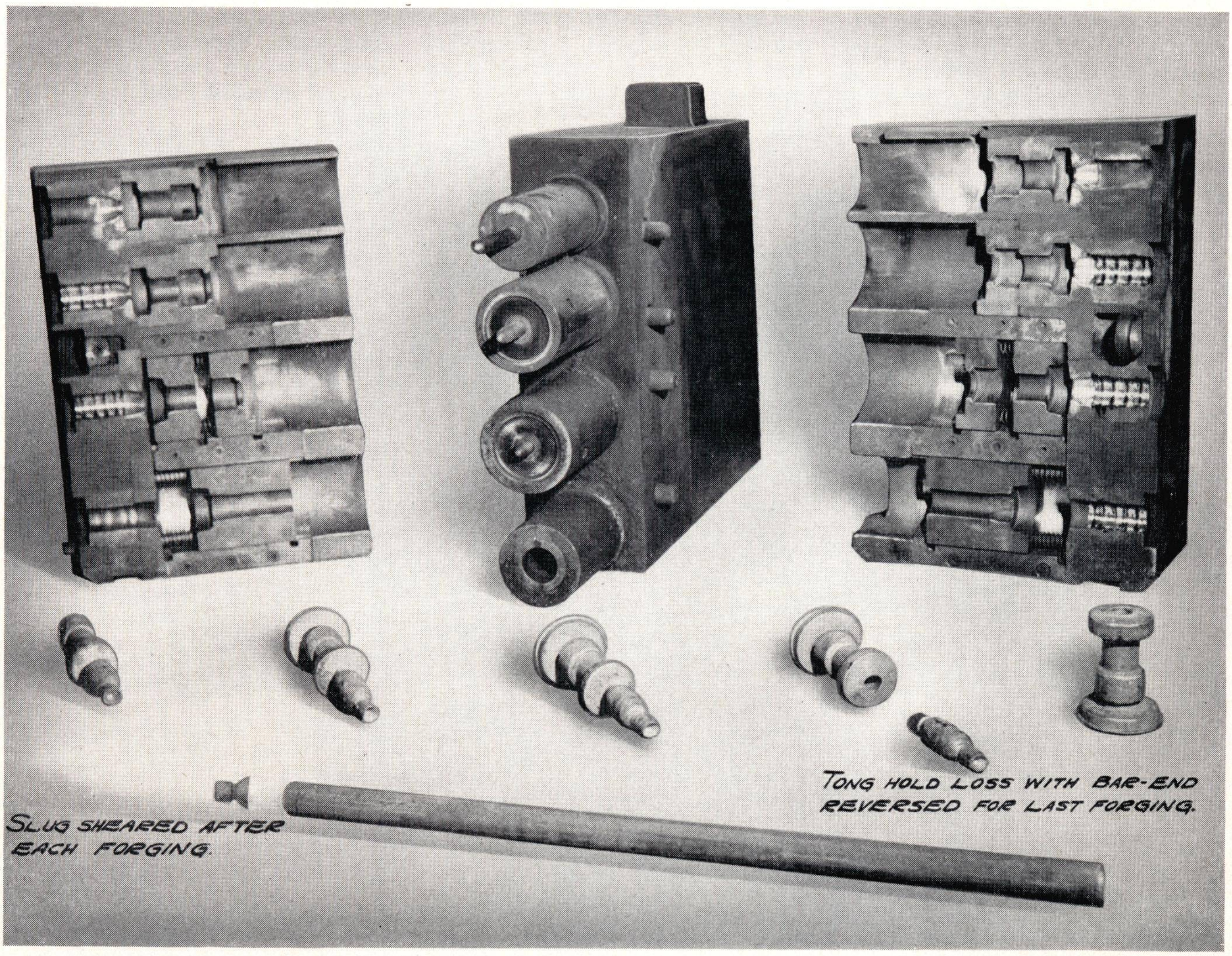


Fig. 36. Dies for upsetting and piercing cluster gear.

fourth operation, penetrates 2½″, displacing metal into the center upset and enlarging the shaft between it and the end gear. The opposite end is then reheated and the blank handled into the second machine on a porter bar with a pin projecting into the hole that is already formed, Fig. 39. It is coned in the second groove from the top, forged and centered in the third groove from the top, pierced to a depth of 2″ in the fourth groove, then pierced to a depth of 4″ in the bottom groove, leaving a ⅜″ thick web between the two holes. Then the flat faced punch at the top removes this web and clears the hole for its entire length of 7″.

The reason for transferring the piece to the top groove for this is because the final punching requires the least pressure and the machine is not capable of doing very heavy work at the top of the dies. Furthermore, in case of breakage, the long punch can be easily replaced if it is in this accessible top position.

Push Extrusion

As contrasted with progressive deep piercing, Fig. 38 shows a series of operations of a novel method of forging the socket on a solid shank shovel by "push extrusion".

A "T" shaped blank is sheared from 11/16″ plate, the design interlocking so there is no waste. The upright of the "T" is then drawn 1⅛″ round in a trip hammer. The cross-arm of the "T" is later fanned out into the shovel blade by rolling. This round is upset to a reverse cone 1⅝″ diameter at the base, and then a 1″ hole is pierced to a depth of about 2½″, leaving a 5/16″ thick wall, the neck still remaining 1⅛″ diameter.

At this point the piece is reheated.

In a second upsetter this heavy walled socket is confined in a die impression with a 1⅛″ orifice between it and the blade section, which is not gripped. A plunger-like tool 1⅝″ diameter, with a 1″ nose, applies pressure to the end of the heavy walled socket, and extrudes the metal out through the opening between the nose and the orifice in the die. This produces a socket 9½″ deep with 1/16″ wall by the method widely known as "push extrusion".

This socket is then, in the same machine, expanded at the mouth, then tapered to conform to the handle, and finally the end collar is trimmed. The nose of the extrusion tool is subjected to but little wear. Die life is greatly helped by proper lubrication and by scale-free heating.

It should be appreciated that the scope of the field of upsetting has been dealt with only superficially, but it is hoped that the examples illustrated, give some idea of the vast possibilities of this method for the economical use of all the various forgeable metals. Bear in mind also, that without exception, the physical properties, dependability, fatigue resistance and durability, are enhanced greatly by forging.

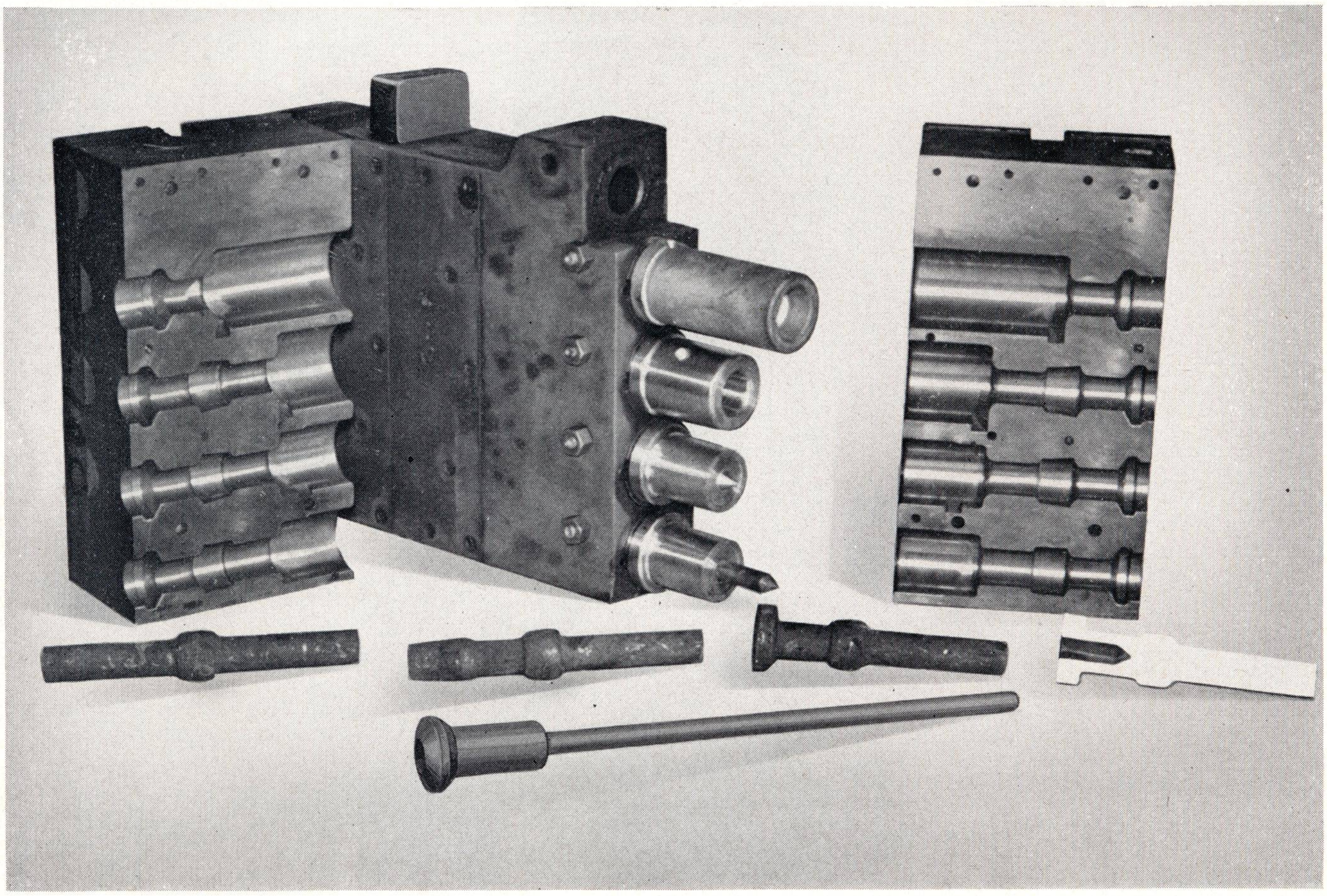


Fig. 37. Dies for upsetting and piercing one end of cluster gear.

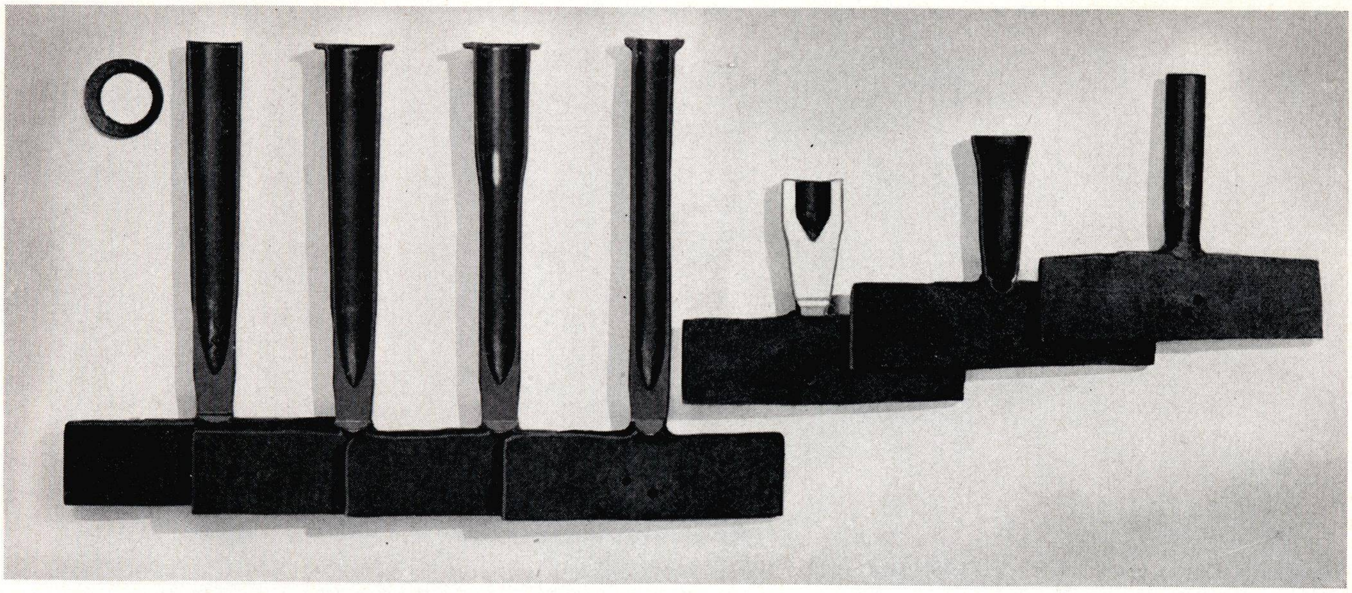


Fig. 38. Forging the socket on a solid shank shovel by "push extrusion".

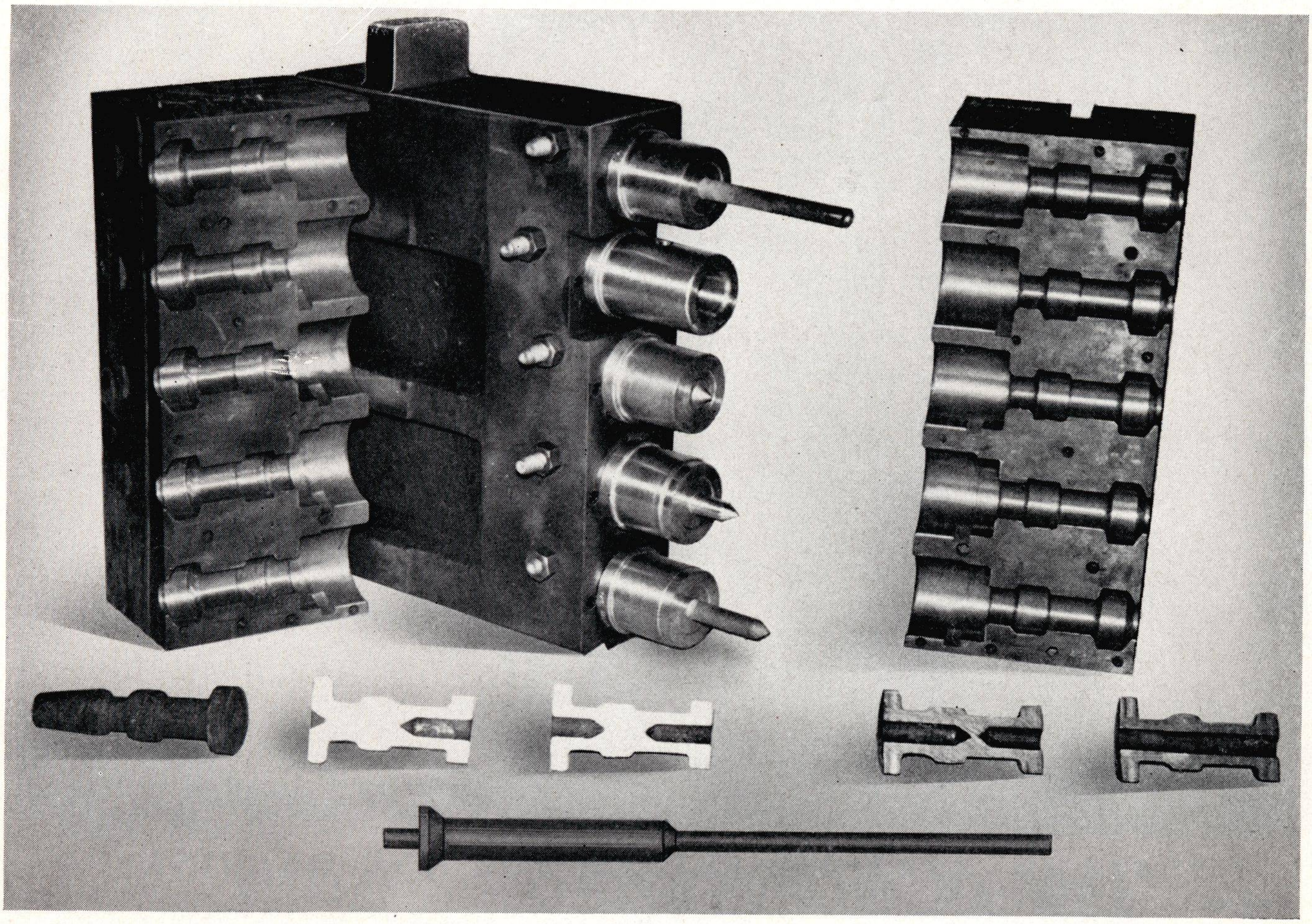


Fig. 39. Dies for upsetting and piercing opposite end of cluster gear.

AJAX HOT METAL WORKING MACHINES

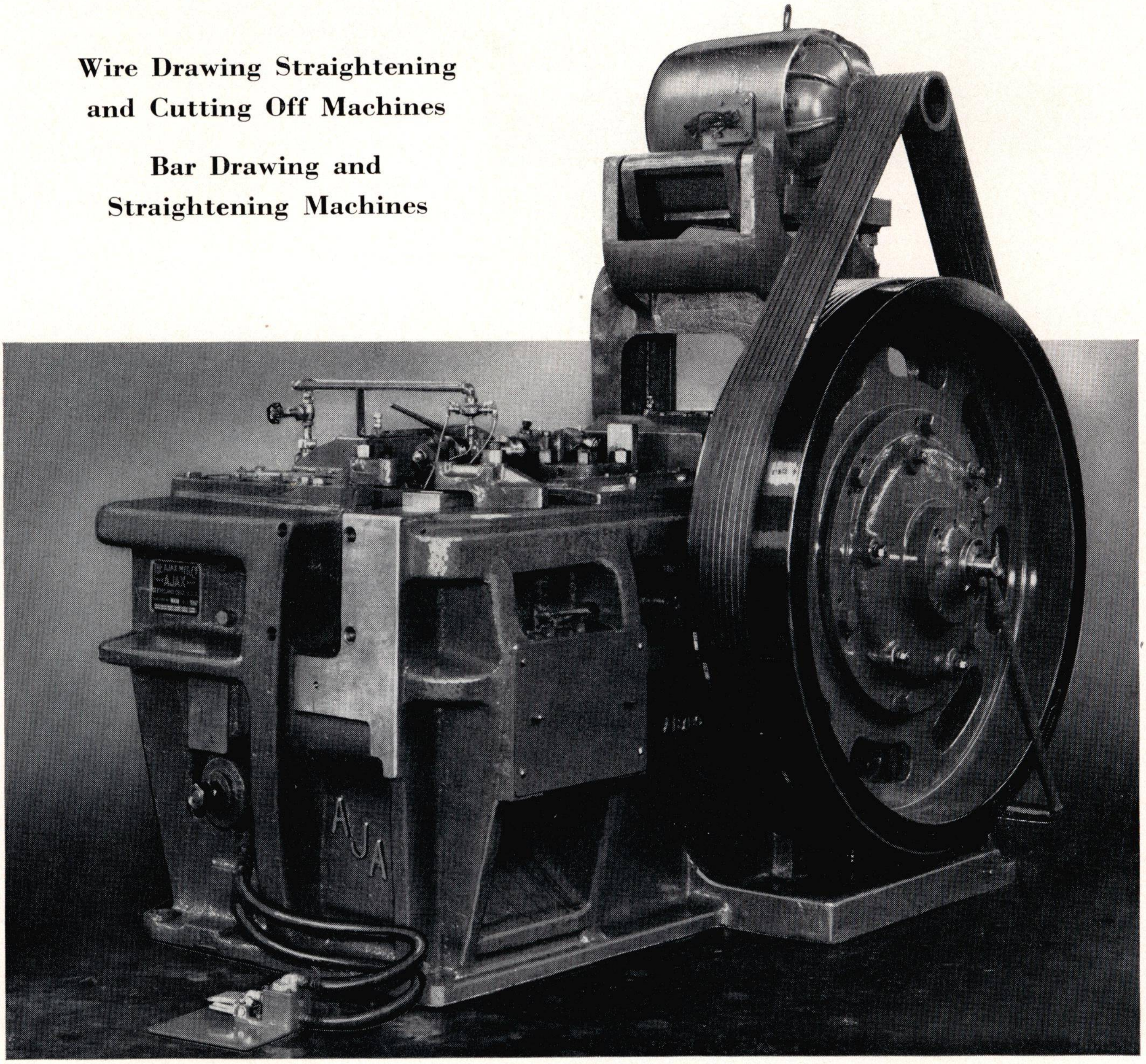
Forging Machines • Forging Presses • Forging Rolls

Bolt and Rivet Heading Machines • • Bulldozers or Bending Machines

Hot Sawing and Burring Machines • Ajax-Hogue Wire Drawers

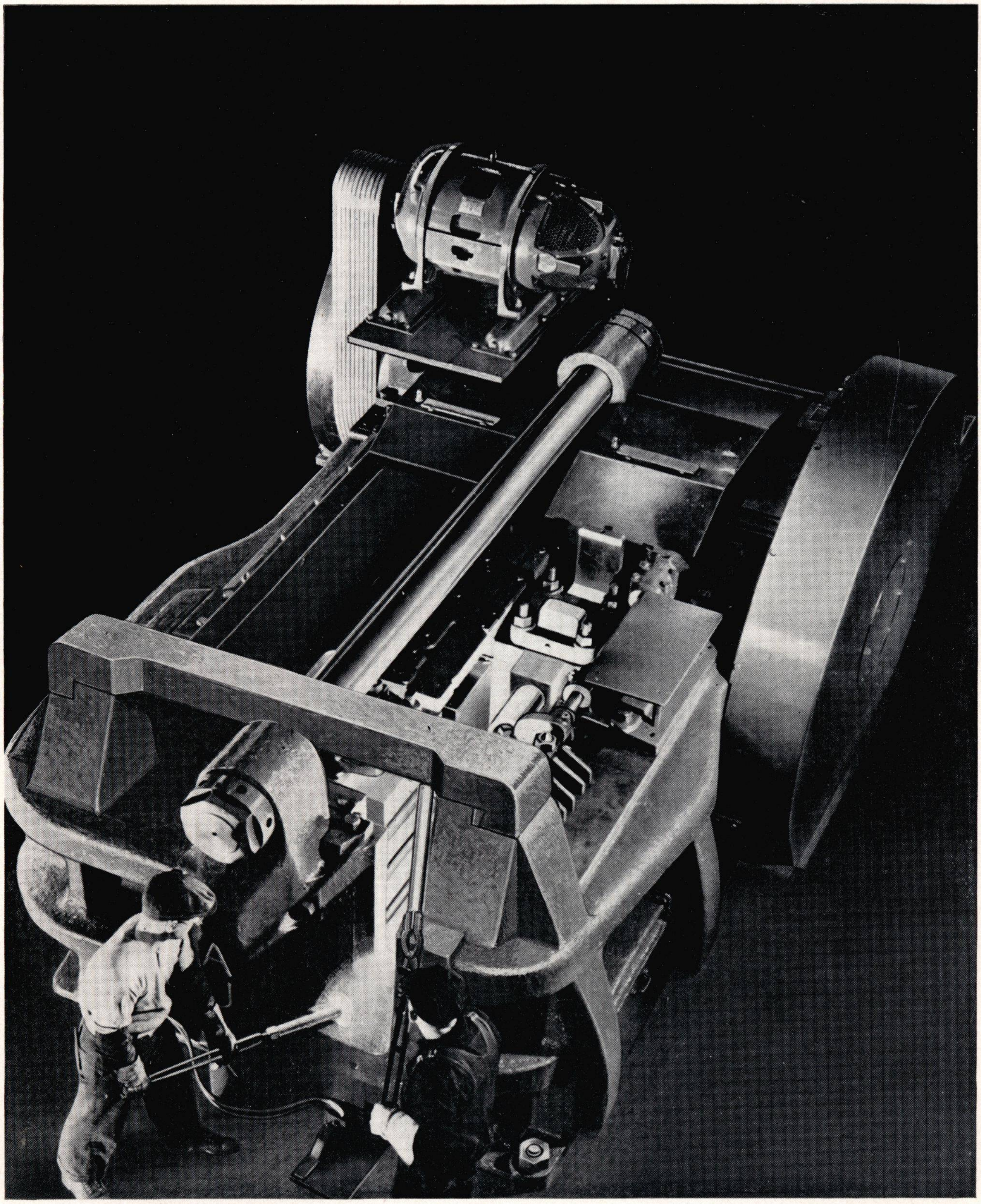
Wire Drawing Straightening and Cutting Off Machines

Bar Drawing and Straightening Machines



1″ and 1½″ AJAX AIR CLUTCH FORGING MACHINES

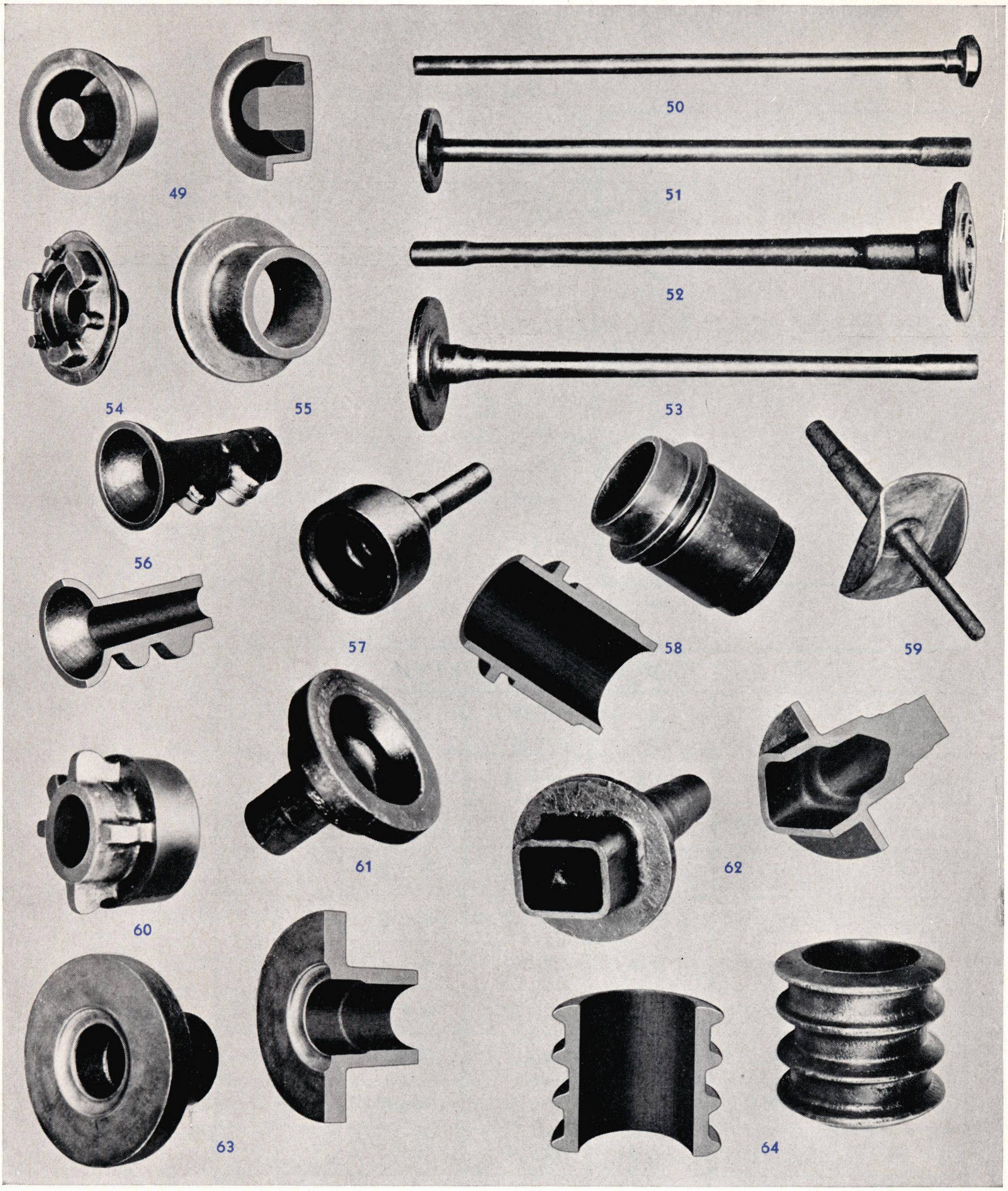
These two smaller sizes possess the outstanding advantages of the large machines but are not back geared because of their smaller power requirements. — Described in Bulletin No. 64.



5″ AJAX AIR CLUTCH FORGING MACHINE

This and other sizes 2″ to 10″ described in Bulletin 65 C

This representative group of upset and pierced forgings produced on Ajax Air Clutch Forging Machines



These heavy forgings are typical of the upsetting and piercing done on Ajax Air Clutch Forging Machines

GRIP DIES FOR FORGING MACHINES

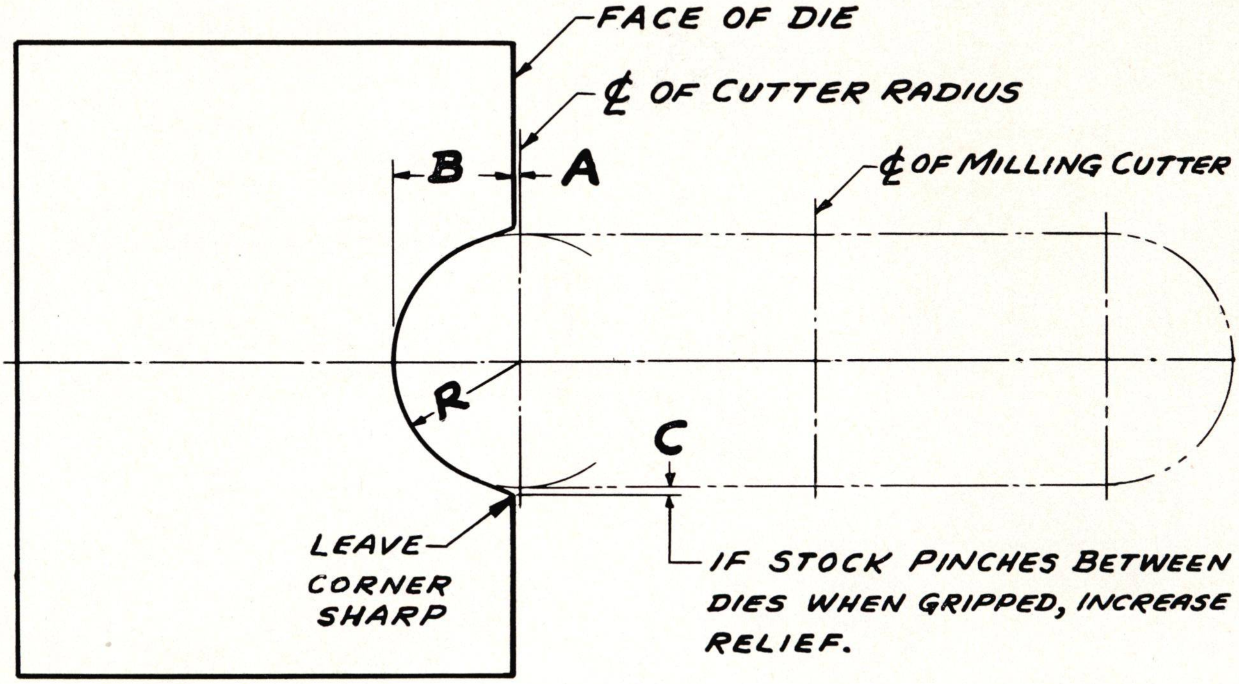


TABLE FOR GRIP GROOVING					
STOCK SIZE	R	A	TOTAL GRIP	B	C
$\frac{1}{2}$"	.250	.002	.004	.248	$\frac{1}{64}$
$\frac{5}{8}$"	.3125	.0025	.005	.310	$\frac{1}{64}$
$\frac{3}{4}$"	.375	.003	.006	.372	$\frac{1}{64}$
$\frac{7}{8}$"	.4375	.0035	.007	.434	$\frac{1}{64}$
1"	.500	.004	.008	.496	$\frac{1}{64}$
$1\frac{1}{4}$"	.625	.005	.010	.620	$\frac{1}{32}$
$1\frac{1}{2}$"	.750	.006	.012	.744	$\frac{1}{32}$
$1\frac{3}{4}$"	.875	.006	.013	.869	$\frac{1}{32}$
2"	1.000	.007	.014	.993	$\frac{1}{32}$
$2\frac{1}{2}$"	1.250	.007	.015	1.243	$\frac{3}{64}$
3"	1.500	.008	.016	1.492	$\frac{3}{64}$

AREAS OF CIRCLES

DIAM.	0	1	2	3	4	5	6	7	8	9	10	11	DIAM.
		.78540	3.1416	7.0686	12.566	19.635	28.274	38.485	50.266	63.617	78.540	95.033	
1/32	.00077	.83525	3.2405	7.2166	12.763	19.881	28.569	38.829	50.659	64.060	79.031	95.574	1/32
1/16	.00307	.88664	3.3410	7.3662	12.962	20.129	28.867	39.175	51.054	64.504	79.525	96.116	1/16
3/32	.00690	.93956	3.4430	7.5173	13.162	20.378	29.165	39.522	51.450	64.950	80.019	96.660	3/32
1/8	.01227	.99402	3.5466	7.6699	13.364	20.629	29.465	39.871	51.849	65.397	80.516	97.206	1/8
5/32	.01917	1.0500	3.6516	7.8241	13.567	20.881	29.766	40.222	52.248	65.845	81.013	97.752	5/32
3/16	.02761	1.1075	3.7583	7.9798	13.772	21.135	30.069	40.574	52.649	66.296	81.513	98.301	3/16
7/32	.03758	1.1666	3.8664	8.1370	13.978	21.391	30.374	40.927	53.052	66.747	82.014	98.850	7/32
1/4	.04909	1.2272	3.9761	8.2958	14.186	21.648	30.680	41.283	53.456	67.201	82.516	99.402	1/4
9/32	.06213	1.2893	4.0873	8.4561	14.396	21.906	30.987	41.639	53.862	67.655	83.020	99.955	9/32
5/16	.07670	1.3530	4.2000	8.6179	14.607	22.166	31.296	41.997	54.269	68.112	83.525	100.510	5/16
11/32	.09281	1.4182	4.3143	8.7813	14.819	22.428	31.607	42.357	54.678	68.570	84.032	101.066	11/32
3/8	.11045	1.4849	4.4301	8.9462	15.033	22.691	31.919	42.718	55.088	69.029	84.541	101.623	3/8
13/32	.12962	1.5532	4.5475	9.1126	15.249	22.955	32.233	43.081	55.500	69.490	85.051	102.182	13/32
7/16	.15033	1.6230	4.6664	9.2806	15.466	23.221	32.548	43.446	55.914	69.953	85.563	102.743	7/16
15/32	.17257	1.6943	4.7868	9.4501	15.684	23.489	32.865	43.811	56.329	70.417	86.076	103.305	15/32
1/2	.19635	1.7671	4.9087	9.6211	15.904	23.758	33.183	44.179	56.745	70.882	86.590	103.869	1/2
17/32	.22166	1.8415	5.0322	9.7937	16.126	24.029	33.503	44.548	57.163	71.349	87.106	104.434	17/32
9/16	.24850	1.9175	5.1572	9.9678	16.349	24.301	33.824	44.918	57.583	71.818	87.624	105.001	9/16
19/32	.27688	1.9949	5.2838	10.143	16.574	24.575	34.147	45.290	58.004	72.288	88.143	105.569	19/32
5/8	.30680	2.0739	5.4119	10.321	16.800	24.850	34.472	45.664	58.426	72.760	88.664	106.139	5/8
21/32	.33824	2.1545	5.5415	10.499	17.028	25.127	34.798	46.039	58.850	73.233	89.186	106.711	21/32
11/16	.37122	2.2365	5.6727	10.680	17.257	25.406	35.125	46.415	59.276	73.708	89.710	107.284	11/16
23/32	.40574	2.3201	5.8053	10.861	17.488	25.686	35.454	46.793	59.703	74.184	90.236	107.858	23/32
3/4	.44179	2.4053	5.9396	11.045	17.721	25.967	35.785	47.173	60.132	74.662	90.763	108.434	3/4
25/32	.47937	2.4920	6.0753	11.230	17.954	26.250	36.117	47.554	60.562	75.141	91.291	109.012	25/32
13/16	.51849	2.5802	6.2126	11.416	18.190	26.535	36.451	47.937	60.994	75.622	91.821	109.591	13/16
27/32	.55914	2.6699	6.3514	11.604	18.427	26.821	36.786	48.321	61.428	76.105	92.353	110.171	27/32
7/8	.60132	2.7612	6.4918	11.793	18.665	27.109	37.122	48.707	61.863	76.589	92.886	110.753	7/8
29/32	.64504	2.8540	6.6337	11.984	18.906	27.398	37.461	49.094	62.299	77.074	93.420	111.337	29/32
15/16	.69029	2.9483	6.7771	12.177	19.147	27.688	37.800	49.483	62.737	77.561	93.956	111.922	15/16
31/32	.73708	3.0442	6.9221	12.371	19.390	27.981	38.142	49.874	63.176	78.050	94.494	112.509	31/32
DIAM.	0	1	2	3	4	5	6	7	8	9	10	11	DIAM.

DECIMAL EQUIVALENTS

1/64 = .0156	17/64 = .2656	33/64 = .5156	49/64 = .7656
1/32 = .0312	9/32 = .2812	17/32 = .5312	25/32 = .7812
3/64 = .0468	19/64 = .2968	35/64 = .5468	51/64 = .7968
1/16 = .0625	**5/16 = .3125**	**9/16 = .5625**	**13/16 = .8125**
5/64 = .0781	21/64 = .3281	37/64 = .5781	53/64 = .8281
3/32 = .0937	11/32 = .3437	19/32 = .5937	27/32 = .8437
7/64 = .1093	23/64 = .3593	39/64 = .6093	55/64 = .8593
1/8 = .125	**3/8 = .375**	**5/8 = .625**	**7/8 = .875**
9/64 = .1406	25/64 = .3906	41/64 = .6406	57/64 = .8906
5/32 = .1562	13/32 = .4062	21/32 = .6562	29/32 = .9062
11/64 = .1718	27/64 = .4218	43/64 = .6718	59/64 = .9218
3/16 = .1875	**7/16 = .4375**	**11/16 = .6875**	**15/16 = .9375**
13/64 = .2031	29/64 = .4531	45/64 = .7031	61/64 = .9531
7/32 = .2187	15/32 = .4687	23/32 = .7187	31/32 = .9687
15/64 = .2343	31/64 = .4843	47/64 = .7343	63/64 = .9843
1/4 = .25	**1/2 = .5**	**3/4 = .75**	**1 = 1.0**

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Printed in U. S. A.